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(71) Applicant(s)
JFE STEEL CORPORATION

(72) Inventor(s)
Oyama, Nobuyuki;Iwasaki, Katsuhiro;Kadoya, Hideki;Nagashima, Yasuo;Tako, Hiroshi

(74) Agent / Attorney
Griffith Hack, GPO Box 4164, Sydney, NSW, 2001

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(71) 出願人 (米国を除く全ての指定国について): **JFE スチール株式会社(JFE STEEL CORPORATION)** [JP/JP]; 〒1000011 東京都千代田区内幸町二丁目２番３号 Tokyo (JP).

(72) 発明者; および
(75) 発明者/出願人 (米国についてのみ): 大山伸幸 **(OYAMA, Nobuyuki)** [JP/JP]; 〒1000011 東京都千代田区内幸町二丁目２番３号 JFEスチール株式会社 知的財産部内 Tokyo (JP). 岩崎克博 **(IWASAKI, Katsuhiro)** [JP/JP]; 〒1000011 東京都千代田区内幸町二丁目２番３号 JFEスチール株式会社 知的財産部内 Tokyo (JP). 角谷秀紀 **(KADOYA, Hideki)** [JP/JP]; 〒1000011 東京都千代田区内幸町二丁目２番３号 JFEスチール株式会社 知的財産部内 Tokyo (JP). 長島康雄 **(NAGASHIMA, Yasuo)** [JP/JP]; 〒1000011 東京都千代田区内幸町二丁目２番３号 JFEスチール株式会社 知的財産部内 Tokyo (JP). 竹生博 **(TAKO, Hiroshi)** [JP/JP]; 〒1000011 東京都千代田区内幸町二丁目２番３号 JFEスチール株式会社 知的財産部内 Tokyo (JP).

(74) 代理人: 落合憲一郎 **(OCHIAI, Kenichiro)**; 〒1030027 東京都中央区日本橋二丁目１番１０号 柳屋ビル7階 JFEテクノリサーチ株式会社 特許出願部内 Tokyo (JP).

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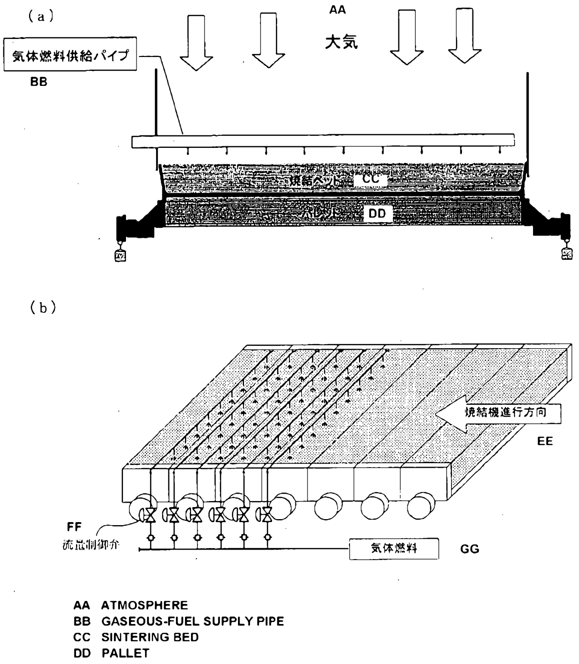
図5



AA ATMOSPHERE
BB GASEOUS-FUEL SUPPLY PIPE
CC SINTERING BED
DD PALLET
EE SINTERING MACHINE ADVANCING DIRECTION
FF FLOW RATE CONTROL VALVE
GG GASEOUS FUEL

(57) Abstract: A process for producing a sintered ore which comprises: a charging step in which a pallet traveling cyclically is charged with a raw sintering material comprising a powdery ore and a carbonaceous material to form a charge layer of the raw sintering material on the pallet; an ignition step in which the carbonaceous material present in the surface of the charge layer is ignited with an ignition furnace; a dilute-gaseous-fuel production step in which a gaseous fuel is supplied to the air present over the charge layer to dilute the fuel and thereby obtain a dilute gaseous fuel having a concentration not higher than the lower combustion limit concentration; and a combustion step in which the dilute gaseous fuel and air are sucked into the charge layer by the suction of a wind box disposed beneath the pallet to burn the dilute gaseous fuel in the sinter layer and, at the same time, burn the carbonaceous material contained in the charge layer with the aid of the air sucked into the charge layer and thereby produce a sinter cake.

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循環移動するパレット上に粉鉱石と炭材を含む焼結原料を装入して、パレット上に焼結原料の装入層を形成する装入工程と、装入層表面の炭材に点火炉を使って点火する点火工程と、気体燃料を装入層上方の空気中に供給して希釈し、燃焼下限濃度以下の希釈気体燃料を得る希釈気体燃料生成工程と、パレット下に配置されたウインドボックスの吸引力により、上記希釈気体燃料と空気とを装入層内に吸引し、該希釈気体燃料を焼結層内において燃焼させると同時に、装入層内に吸引した空気により、該装入層内の炭材を燃焼させることにより、焼結ケーキを生成させる燃焼工程とを有する焼結鉱の製造方法。

DESCRIPTION

METHOD FOR PRODUCING SINTERED ORE AND SINTERING MACHINE

FIELD OF THE INVENTION

The present invention relates to methods for producing a sintered ore used as a raw material for blast furnaces using a downdraft Dwight-Lloyd (DL) sintering machine and also relates to sintering machines used for such methods.

DESCRIPTION OF THE RELATED ARTS

Sintered ore, serving as a main raw material for blast furnace iron making, is produced by steps shown in Fig. 1. The raw materials include iron ore fines, recovered fines in steel works, under-sieve fines of sintered ore, CaO-containing auxiliary raw materials such as limestone and dolomite, a granulation aid such as burnt lime, coke fines, and anthracite. These raw materials are fed from hoppers 1 onto a conveyer in predetermined proportions. The fed raw materials are mixed and granulated in, for example, a drum mixer 2 where an appropriate amount of water is added thereto, thus forming a sintering raw material in the form of quasi-particles having a mean size of 3.0 to 6.0 mm. This sintering raw material is charged onto an endless moving sintering machine pallet 8 from surge hoppers 4 and 5 disposed above the sintering machine via a drum feeder 6 and a charging chute 7, thus forming a charged bed, also called a sintering bed. The thickness (height) of the sintering bed is about 400 to 800 mm. Subsequently, the carbonaceous material in the surface layer of the sintering bed is ignited by an ignition furnace 10 disposed above the sintering bed 9 and is sequentially combusted by air sucked downward through wind boxes 11 disposed under the pallet 8, when combustion heat is generated so that the sintering raw material is combusted and melted, thus forming a sinter cake. The resultant sinter cake is then crushed and regularly sized and is recovered as a sintered ore product composed of agglomerates having a size of 5.0 mm or more.

In the above production process, first, the ignition furnace 10 ignites the surface layer of the sintering bed. The carbonaceous material in the ignited sintering bed is successively combusted by air sucked downward from the upper layer to the lower layer of the sintering bed through the wind boxes, with the combustion zone gradually moving downward and frontward (downstream) as the pallet 8 moves. As the combustion proceeds, moisture contained in the sintering raw material particles in the sintering bed is vaporized by heat generated by the combustion of the carbonaceous material and is sucked downward to form a wet zone where the moisture concentrates in the sintering raw material in the lower layer, where the temperature has yet to be increased. When the moisture concentration reaches or exceeds a certain level, the moisture fills voids between the raw material particles, which serve as channels for the suction gas, thus increasing the airflow resistance. The airflow resistance is also increased by the melted portion, which is necessary for the sintering reaction occurring in the combustion zone.

The production capacity (t/hr) of a sintering machine is generally determined by the product of sinter productivity (t/hr·m^2) and the area of the sintering machine (m^2). That is, the production capacity of a sintering machine varies with, for example, the width and length of the sintering machine, the thickness of the charged bed (the thickness of the sintering bed), the bulk density of the sintering raw material, sintering (combustion) time, and yield. To increase the amount of sintered ore produced, for example, it is thought to be effective to improve the permeability (pressure loss) of the sintering bed to shorten the combustion time, or to increase the cold strength of sinter cake before crushing to improve the yield.

Fig. 2 shows pressure loss and temperature distributions in a sintering bed having a height of 600 mm, where a combustion (flame) front propagating through the sintering bed is located at a position about 400 mm from the pallet (200 mm from the surface of the sintering bed) in the sintering bed. In this case, about 60% of the pressure loss distribution is in the wet zone, and about 40% is in the combustion and melting zone.

Fig. 3 shows temperature distributions in sintering beds for high production and low production of sintered ore.

The time during which the sintering raw material is maintained at a temperature of 1,200°C or more, where the particles of the sintering raw material start melting (hereinafter referred to as "high-temperature-zone holding time"), is denoted by t_1 for low production and is denoted by t_2 for high production, where productivity is given priority. For high production, the high-temperature-zone holding time t_2 is shorter than the high-temperature-zone holding time t_1 for low production because the pallet traveling speed is increased. As the high-temperature-zone holding time becomes shorter, the cold strength of sintered ore is decreased because of insufficient firing, thus decreasing the yield. To increase the amount of high-strength sintered ore produced, therefore, some means must be taken for increasing the strength of sinter cake, namely, the cold strength of sintered ore, in short-time sintering to maintain and improve the yield. As the indices indicating the cold strength of a sintered ore, in general, SI (shutter index) and TI (tumbler index) have been used.

Fig. 4(a) shows the sintering process of the sintering bed on the sintering machine pallet, Fig. 4(b) shows the temperature distribution (heat pattern) in the sintering bed during the sintering process, and Fig. 4(c) shows the yield distribution of sinter cake. As shown in Fig. 4(b), the temperature of the sintering bed is less easily increased in the upper portion than in the lower layer, and the high-temperature-zone holding time is correspondingly shorter.

This results in an insufficient combustion/melting reaction (sintering reaction) in the upper portion of the sintering bed, thus decreasing the strength of sinter cake and therefore decreasing the yield and the productivity, as shown in Fig. 4(c).

In light of such problems, some methods for maintaining high temperature in the upper layer of the sintering bed have been proposed. Patent Document 1, for example, discloses a technique of ejecting a gaseous fuel onto a sintering bed after the ignition of the sintering bed. According to the above technique, however, a gaseous fuel (flammable gas), which is not specified and is possibly propane gas (LPG) or natural gas (LNG), is used in high concentrations. In addition, the flammable gas is injected without reducing the amount of carbonaceous material, so that the sintering bed reaches a high temperature exceeding 1,380°C. Thus, this technique does not provide a sufficient effect of improving cold strength and yield. Furthermore, this technique is impractical and has yet to be put into practice because the ejection of the flammable gas immediately behind the ignition furnace poses a high risk of a fire in the space above the sintering bed due to combustion of the flammable gas.

Patent Document 2 also discloses a technique of adding a flammable gas to air sucked into the sintering bed after the ignition of the sintering bed. It discloses that the flammable gas is preferably supplied for about one to ten minutes after the ignition, although the sintered ore remains red-hot in the surface layer immediately after the ignition by the ignition furnace and, depending on the manner of supply, poses a high risk of a fire due to combustion of the flammable gas. In addition, although there is little specific description, the combustion of the flammable gas in the sinter zone, where sintering is completed, is ineffective and tends to decrease the productivity because the permeability is degraded by the temperature rise and thermal expansion due to the combustion gas. Thus, this technique has yet to be put into practice. Furthermore, because this is a proposal to add a flammable gas in a normal sintering operation, the temperature during the sintering operation is increased by the calorific value equivalent to the amount of flammable gas added, and a problem arises in that the resultant sintered ore has increased strength but degraded reducibility.

In addition, Patent Document 3 discloses a technique of injecting a mixture of air and coke oven gas immediately behind the ignition furnace through a hood disposed above the sintering bed of the sintering raw material to heat the sintering bed to high temperature. Again, this technique cannot achieve the effect of injecting coke oven gas since the combustion and melting zone in the sintering bed reaches a high temperature exceeding 1,380°C, and has yet to be put into practice because it poses a risk of a fire due to ignition of the flammable mixed gas in the space above the sintering bed.

In addition, Patent Document 4 discloses a method of simultaneously injecting a low-melting-point flux, a carbonaceous material, and a flammable gas immediately behind the ignition furnace. Again, this method poses a high risk of a fire in the space above the sintering bed because the flammable gas is injected into the surface while a fire remains therein and does not achieve a sufficient effect of injecting the flammable gas because the width of the sinter zone cannot be sufficiently increased (less than about 15 mm). Furthermore, the large amount of low-melting-point flux causes excessive melting in the upper layer and therefore blocks pores, serving as air channels, and degrades the permeability, thus decreasing the productivity. Accordingly, this technique has so far yet to be put into practice.

As described above, none of the conventional techniques so far proposed has been put into practice, and there is a need for the development of a feasible flammable gas injection technique.

Patent Document 1: Japanese Unexamined Patent Application Publication No. 48-18102

Patent Document 2: Japanese Examined Patent Application Publication No. 46-27126

Patent Document 3: Japanese Unexamined Patent Application Publication No. 55-18585

Patent Document 4: Japanese Unexamined Patent

Application Publication No. 5-311257

Control of the ultimate maximum temperature during combustion and the high-temperature-zone holding time is important because they determine the quality of sintered ore. In this regard, the method disclosed in Patent Document 1 is a technique for increasing the temperature of the upper portion of the sintering bed in the first half of the sintering process by combusting a gaseous fuel at the surface of the sintering bed. This method, however, has a problem in that it may cause a deficiency of air (oxygen) supporting the combustion due to the high concentration of gaseous fuel and may therefore result in insufficient combustion of the carbonaceous material (coke) in the sintering raw material, thus failing to improve the quality of sintered ore.

In addition, Patent Document 2 lacks specifics and has so far yet to be put into practice because it poses a high risk of a fire, depending on the manner of supply, and the combustion of a flammable gas in the sinter zone, where sintering is completed, is ineffective.

In addition, the method disclosed in Patent Document 3 is a technique of injecting a mixture of air and coke oven gas immediately behind the ignition furnace through a hood disposed above the sintering bed of the sintering raw material to heat the sintering bed to high temperature. However, if the mixed gas is injected in the same coke proportion, a large amount of vitreous low-strength mineral is formed because the ultimate maximum temperature rises as the high-temperature holding time is extended, and consequently the effect of injecting the mixed gas cannot be achieved. In addition, this technique has yet to be put into practice because it poses a risk of a fire due to ignition of the flammable mixed gas.

In addition, the method disclosed in Patent Document 4 increases the combustion speed of a flammable gas and coke by mixing a low-melting-point flux and a carbonaceous material while increasing the amount of air (oxygen), although it has a problem in that the permeability for combustion air is decreased because the low-melting-point flux and the fines are injected together.

It is to be understood that a reference herein to a prior art publication does not constitute an admission that the publication forms a part of the common general knowledge in the art, in Australia or any other country.

SUMMARY OF THE INVENTION

It would be advantageous if at least preferred embodiments of the present invention provide a method for producing sintered ore that allows a high-strength sintered ore to be produced in high yield by supplying a gaseous fuel and combusting it in a sintering bed without degrading the permeability of the entire sintering bed, and to provide a sintering machine that is used for the method.

In a first aspect, the present invention provides a method for producing sintered ore, comprising:

a charging step of charging a sintering raw material containing ore fines and a carbonaceous material onto a circulating pallet to form a sintering bed of the sintering raw material on the pallet;

an ignition step of igniting the carbonaceous material on a surface of the sintering bed;

a diluted gaseous fuel producing step of producing a diluted gaseous fuel having a concentration of a lower flammable limit concentration or less by supplying a gaseous fuel to air above the sintering bed at a flow speed at which a blow-off occurs to dilute the gaseous fuel;

and

a combustion step of combusting, in the sintering bed, the diluted gaseous fuel and the carbonaceous material contained in the sintering bed by sucking the diluted gaseous fuel and air into the sintering bed through a wind box disposed below the pallet, thereby forming a sinter cake.

The diluted gaseous fuel producing step comprises producing a diluted gaseous fuel having a concentration of a lower flammable limit concentration or less by supplying a gaseous fuel to air above the sintering bed at a flow speed at which a blow-off occurs to dilute the gaseous fuel. The flow speed at which a blow-off occurs is preferably a speed exceeding the burning velocity of the gaseous fuel.

The diluted gaseous fuel producing step preferably comprises producing a diluted gaseous fuel having a concentration of a lower flammable limit concentration or less by ejecting a gaseous fuel into air above the sintering bed at a speed twice or more the burning velocity of the gaseous fuel to dilute the gaseous fuel. More preferably, the diluted gaseous fuel producing step comprises producing a diluted gaseous fuel having a concentration of a lower flammable limit concentration or less by ejecting a gaseous fuel into air above the sintering bed at a speed twice or more the turbulent burning velocity of the gaseous fuel to dilute the gaseous fuel. For example, methane gas has a laminar burning velocity of about 0.4 m/s and a turbulent burning velocity of about 4 m/s.

The diluted gaseous fuel producing step preferably comprises producing a diluted gaseous fuel having a concentration of a lower flammable limit concentration or less by ejecting a gaseous fuel into air above the sintering bed at a pressure of 300 mmAq to less than 40,000 mmAq with respect to an ambient pressure to dilute the gaseous fuel.

The diluted gaseous fuel producing step preferably comprises ejecting a gaseous fuel from an outlet having an opening diameter of less than 3 mm into air above the sintering bed. More preferably, the opening diameter is 0.5 to 1.5 mm.

To control the heat pattern in the combustion step, the method for producing sintered ore preferably further comprises the step of:

(a) adjusting at least one of the ultimate maximum temperature and the high-temperature-zone holding time in the sintering bed;

(b) adjusting the ultimate maximum temperature in the sintering bed by adjusting the amount of diluted gaseous fuel supplied or the concentration of the diluted gaseous fuel;

(c) adjusting the ultimate maximum temperature in the sintering bed by adjusting the amount of carbonaceous material contained in the sintering raw material;

(d) adjusting the ultimate maximum temperature to 1,205°C to 1,380°C by adjusting at least one of the amount of diluted gaseous fuel supplied, the concentration of the diluted gaseous fuel, and the amount of carbonaceous material contained in the sintering raw material;

(e) adjusting the high-temperature-zone holding time in the sintering bed depending on the amount of diluted gaseous fuel supplied, the concentration of the diluted gaseous fuel, or the amount of carbonaceous material contained in the sintering raw material; or

(f) adjusting the high-temperature-zone holding time in the sintering bed by adjusting the amount of diluted gaseous fuel supplied or the concentration of the diluted gaseous fuel depending on the amount of carbonaceous material contained in the sintering raw material.

The method for producing sintered ore preferably further comprises the step of adjusting the shape of a combustion and melting zone in the sintering bed by combusting the diluted gaseous fuel introduced from above the sintering bed. The step of adjusting the shape of the combustion and melting zone preferably comprises adjusting the thickness of the combustion and melting zone in a height direction and/or the width of the combustion and melting zone in a movement direction of the pallet by combusting the diluted gaseous fuel introduced from above the sintering bed.

The method for producing sintered ore preferably further comprises the step of adjusting a position where the diluted gaseous fuel is introduced into the sintering bed.

The method for producing sintered ore preferably further comprises the step of adjusting the cold strength of sintered ore.

The combustion step of combusting the diluted gaseous fuel and the carbonaceous material in the sintering bed to form a sinter cake is preferably as follows:

(A) The combustion step comprises combusting the diluted gaseous fuel so that at least a portion of the diluted gaseous fuel introduced from above the sintering bed reaches a combustion and melting zone in the sintering bed while remaining unburned;

(B) The combustion step preferably comprises combusting the diluted gaseous fuel in the sintering bed to extend the high-temperature-zone holding time of a combustion and melting zone, thereby adjusting the cold strength of sintered ore;

(C) The combustion step comprises combusting the diluted gaseous fuel in the sintering bed by sucking the diluted gaseous fuel into the sintering bed at a position downstream of an ignition furnace;

(D) The combustion step comprises combusting the diluted gaseous fuel in the sintering bed by sucking the diluted gaseous fuel into the sintering bed during a period of time after formation of a sinter cake in a surface layer of the sintering bed until burn-through;

(E) The combustion step comprises combusting the diluted gaseous fuel in the sintering bed by sucking the diluted gaseous fuel into the sintering bed in a region where the thickness of a combustion and melting zone is 15 mm or more;

(F) The combustion step comprises combusting the diluted gaseous fuel in the sintering bed by sucking the diluted gaseous fuel into the sintering bed downstream of a position where a combustion front has reached 100 mm below a surface of the sintering bed; or

(G) The combustion step comprises combusting the diluted gaseous fuel in the sintering bed by sucking the diluted gaseous fuel into the sintering bed near both sidewalls.

The diluted gaseous fuel is preferably a flammable gas diluted to a concentration of 75% to 2% of the lower flammable limit concentration, more preferably, a flammable gas diluted to a concentration of 60% to 2% of the lower flammable limit concentration, and most preferably a flammable gas diluted to a concentration of 25% to 2% of the lower flammable limit concentration.

The gaseous fuel supplied to the sintering bed is preferably:

(a) a flammable gas selected from the group consisting of blast furnace gas, coke oven gas, a mixture of blast furnace gas and coke oven gas, town gas, natural gas, methane gas, ethane gas, propane gas, and a mixture thereof;

(b) one of town gas and propane gas;

(c) a gas having a CO content of 50 ppm by mass or less; or

(d) a vapor of a liquid fuel having an ignition temperature in vapor phase higher than the temperature of a surface layer of the sintering bed. The liquid fuel is one selected from the group consisting of alcohols, ethers, petroleum oils, and other hydrocarbon compounds.

In a second aspect, the present invention provides a sintering machine comprising:

a circulating pallet;

a sintering raw material supply unit for charging a sintering raw material containing ore fines and a carbonaceous material onto the pallet to form a sintering bed;

an ignition furnace for igniting the carbonaceous material in the sintering raw material;

a wind box disposed below the pallet; and

a gaseous fuel supply unit, disposed downstream of the ignition furnace in an advancing direction of the pallet, for ejecting a gaseous fuel into air above the sintering bed so as to mix the gaseous fuel with air,

the gaseous fuel supply unit comprising gaseous fuel supply pipes and ejection means for ejecting the gaseous fuel provided in the pipes, the ejection means including one selected from the group consisting of slits, openings, and nozzles, the ejection means having an opening diameter of 0.5 to 3 mm.

The gaseous fuel supply unit preferably ejects a gaseous fuel into air above the sintering bed so as to mix the gaseous fuel with air, thereby preparing a diluted gaseous fuel in a concentration at or below a lower flammable limit concentration.

The gaseous fuel supply unit is preferably as follows:

(a) The gaseous fuel supply unit comprises a plurality of gaseous fuel supply pipes disposed along a width direction of the pallet and ejection means, for ejecting the gaseous fuel, provided in the pipes and including one selected from the group consisting of slits, openings, and nozzles;

(b) The gaseous fuel supply unit includes a plurality of gaseous fuel supply pipes disposed along the movement direction of the pallet and ejection means, for ejecting the gaseous fuel, provided in the pipes and including one selected from the group consisting of slits, openings, and nozzles;

(d) The gaseous fuel supply unit comprises a control device for controlling the amount of gaseous fuel supplied in a width direction of the pallet;

(e) The gaseous fuel supply unit comprises a fuel concentration control device for maintaining a constant fuel concentration per amount of suction air by supplying a larger amount of fuel to a portion having a higher suction speed and supplying a smaller amount of fuel to a portion having a lower suction speed, depending on the distribution of the suction speed in a width direction of the pallet;

(f) The gaseous fuel supply unit is a gaseous fuel supply unit for ejecting the gaseous fuel downward toward the sintering bed;

(g) The gaseous fuel supply unit is a gaseous fuel supply unit for ejecting the gaseous fuel in parallel with a surface of the sintering bed;

(h) The gaseous fuel supply unit is a gaseous fuel supply unit for ejecting the gaseous fuel toward a reflective plate;

(i) The gaseous fuel supply unit includes gaseous fuel supply pipes and gas ejection slits, openings, or nozzles provided in the gaseous fuel supply pipes, and the slits, openings, or nozzles are directed toward a surface of the sintering bed so as to diverge in the range of ±90° with respect to a perpendicular direction;

(j) The gaseous fuel supply unit includes gaseous fuel supply pipes rotatable about axes thereof;

(k) The gaseous fuel supply unit has gaseous fuel outlets at a height of 300 mm or more above a surface of the sintering bed; or

(l) The gaseous fuel supply unit has a lifting and lowering mechanism capable of adjusting a position where the gaseous fuel is ejected to a height of 300 mm or more above a surface of the sintering bed.

The gaseous fuel supply unit is preferably disposed as follows:

(A) At least one gaseous fuel supply unit is disposed downstream of the ignition furnace in a length direction of the sintering machine;

(B) The gaseous fuel supply unit is disposed at a position between a position where a combustion front has propagated below a surface of the sintering bed to a burn-through position in a movement direction of the pallet; or

(C) The gaseous fuel supply unit is disposed near sidewalls.

According to the present invention, in the operation of a downdraft sintering machine, a diluted gaseous fuel can be supplied (introduced) to a sintering bed and combusted at a target position in the sintering bed by ejecting a gaseous fuel into air above the sintering bed so as to dilute and adjust it to a predetermined concentration. In this case, additionally, the position where the diluted gaseous fuel is supplied and the ultimate maximum temperature and high-temperature-zone holding time during the combustion can be controlled to perform an operation that increases the sintered ore strength not only in the upper portion of the sintering bed, where the cold strength of sintered ore tends to be lower because of insufficient combustion, but also at any position in the middle and lower layers of the sintering bed. In the present invention, additionally, the strength of sinter cake can be controlled at any position without degrading the permeability of the entire sintering bed, particularly by controlling the reaction in the combustion and melting zone, for example, controlling the thickness of the zone in the vertical direction and the width in the movement direction of the pallet, so that a sintered ore product with high cold strength can be produced in high yield with high productivity as a whole. Using the sintering machine of the present invention, such a sintering machine operation can be stably performed.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a diagram illustrating a sintering process.

Fig. 2 is a graph illustrating pressure loss and temperature distributions in a sintering bed.

Fig. 3 is an explanatory diagram comparing temperature distributions in high production and low production.

Figs. 4(a) to 4(c) are graphs of temperature and yield distributions in a sintering machine.

Figs. 5(a) and 5(b) are diagrams illustrating an example of a gaseous fuel supply unit according to the present invention.

Figs. 6(a) and 6(b) are diagrams illustrating another example of a gaseous fuel supply unit according to the present invention.

Figs. 7(a) and 7(b) are diagrams illustrating an experiment for examining the effect of the position where a gaseous fuel is supplied on sinter cake.

Fig. 8 is a diagram illustrating a method according to the present invention for ejecting a gaseous fuel vertically downward.

Fig. 9 is a diagram illustrating a method according to the present invention for ejecting a gaseous fuel in the horizontal direction.

Fig. 10 is a diagram illustrating a method according to the present invention for ejecting a gaseous fuel diagonally upward so that the gaseous fuel is mixed by baffle plates.

Fig. 11 is a diagram illustrating a method according to the present invention for ejecting a gaseous fuel so that the gaseous fuel diverges in multiple directions.

Fig. 12 is a set of graphs showing the effects of the ejection speed of a gaseous fuel and the diameter of nozzles according to the present invention on the concentration distribution of diluted gas.

Fig. 13 is a diagram illustrating the influence of crosswinds on the supply of a gaseous fuel according to the present invention.

Fig. 14 is a diagram illustrating the effect of partitions on crosswinds according to the present invention.

Fig. 15 is a diagram illustrating the seal structure of the bottom end of a hood.

Fig. 16 is a diagram illustrating the seal structure of the bottom end of a hood.

Fig. 17 is a diagram illustrating a model of a gaseous fuel supply unit used for analysis and a hood disposed thereabove according to the present invention.

Fig. 18 is a diagram showing analytical results of gaseous fuel concentration distribution according to the present invention.

Fig. 19 is a diagram showing analytical results of pressure distribution according to the present invention.

Fig. 20 is a diagram showing analytical results of gas flow velocity distribution according to the present invention according to the present invention.

Fig. 21 is a vector diagram of gas flow velocity according to the present invention.

Fig. 22 is a diagram illustrating an example of a measure against crosswinds according to the present invention.

Fig. 23 is a diagram illustrating another example of a measure against crosswinds according to the present invention.

Fig. 24 is a diagram illustrating another example of a measure against crosswinds according to the present invention.

Fig. 25 is a diagram illustrating another example of a measure against crosswinds according to the present invention.

Fig. 26 is a diagram illustrating another example of a measure against crosswinds according to the present invention.

Fig. 27 is a diagram illustrating a gaseous fuel supply process according to the present invention.

Fig. 28 is a diagram (photographs) showing variations in a combustion and melting zone in a test pot due to injection of M-gas.

Fig. 29 is a set of graphs illustrating the effects of injection of M-gas on sinter operation conditions and sinter properties.

Fig. 30 is a graph illustrating a method for determining the flammable limits of blast furnace gas.

Fig. 31 is a graph showing the temperature dependence of the lower flammable limit concentration of methane gas.

Fig. 32 is a graph illustrating the relationship between temperature and the combustible component (combustion gas) concentration of a gaseous fuel in air at normal temperature.

Fig. 33 is a diagram showing the relationship between the effect of injection of a diluted gaseous fuel according to the present invention and the type of gas.

Fig. 34 is a set of graphs showing the relationships between the gas concentration of injected propane gas according to the present invention and the shutter index, yield, sintering time, and production.

Fig. 35 is a diagram illustrating a sintering reaction.

Fig. 36 is a phase diagram illustrating how skeleton-crystal secondary hematite is formed.

Fig. 37 is a diagram (photographs) showing the forms of combustion zones observed after the injection of a diluted propane gas.

Fig. 38 is a diagram (photographs) showing the effect of the injection position on combustion condition.

Fig. 39 is a diagram showing the effect of the injection position on combustion condition.

Fig. 40 is a diagram (photographs) comparing the combustion conditions of a conventional sintering method and a method of the present invention with injection of a diluted gas, observed using a thermoviewer in a sintering test using a quartz glass test pot.

Fig. 41 is a graph comparing the temperature distributions in the quartz glass test pot of the conventional sintering method and the method of the present invention with injection of a diluted gas.

Fig. 42 is a graph illustrating temperature distributions in a sintering bed during sintering.

Fig. 43 is an explanatory diagram comparing the combustion conditions of an example where only coke fines were used and an example where coke fines were used in combination with injection of C-gas.

Figs. 44(a) to 44(d) are graphs showing changes over time in the temperature in the sintering bed, the temperature of exhaust gas, the volume of air passed, and the composition of exhaust gas due to injection of a diluted propane gas with the calorific value supplied remaining constant.

Figs. 45(a), 45(b), 45(a'), and 45(b') are graphs showing changes over time in the temperature in the sintering bed and the temperature of exhaust gas in the case where a diluted propane gas was injected (0.5% by volume) and in the case where the amount of coke was merely increased (10% by mass).

Fig. 46 is a set of graphs showing the test results of sintering property tests under various injection conditions.

Fig. 47 is a graph showing variations in the ore phase composition of sintered ore products under various injection conditions.

Fig. 48 is a graph showing variations in the apparent specific gravity of sintered ore products with and without injection of propane gas.

Fig. 49 is a graph showing variations in the distribution of pores with diameters of 0.5 mm or less measured using a mercury intrusion porosimeter with and without injection of propane gas.

Figs. 50(a) and 50(b) are schematic diagrams showing sintering behaviors in the case where coke was used alone and the case where coke was used in combination with a diluted gaseous fuel.

Fig. 51 is a graph showing variations in the pore distribution of sintered ore in the case where a diluted gaseous fuel was injected.

Fig. 52 is a set of graphs showing the results of an experiment for determining a critical coke proportion at which the cold strength can be maintained.

Fig. 53 is a diagram (photographs) showing the results of Example 1.

Fig. 54 is a diagram (photographs) showing the results of Example 2.

EMBODIMENTS FOR CARRYING OUT THE INVENTION

A method for producing sintered ore according to the present invention includes a charging step, an ignition step, a diluted gaseous fuel producing step, and a combustion step. The charging step is a step of charging a sintering raw material containing ore fines and a carbonaceous material onto a circulating pallet to form a sintering bed of the sintering raw material on the pallet. The ignition step is a step of igniting the carbonaceous material on a surface of the sintering bed using an ignition furnace. The diluted gaseous fuel producing step is a step of preparing a diluted gaseous fuel in a concentration at or below a lower flammable limit concentration by supplying a gaseous fuel to air above the sintering bed so as to dilute the gaseous fuel. The combustion step is a step of combusting the diluted gaseous fuel in the sintering bed by sucking the diluted gaseous fuel and air into the sintering bed by suction through a wind box disposed below the pallet while combusting the carbonaceous material in the sintering bed with the air sucked into the sintering bed to sinter the sintering raw material with combustion heat generated thereby, thus forming a sinter cake. The present invention is characterized by the diluted gaseous fuel producing step and the combustion step.

The diluted gaseous fuel producing step is a step of preparing a diluted gaseous fuel in a concentration at or below a lower flammable limit concentration by ejecting a gaseous fuel at high speed into air above the sintering bed downstream of the ignition furnace in the movement direction of the pallet so as to mix the gaseous fuel with air before introducing the diluted gaseous fuel into the sintering bed. A sintering machine of the present invention is characterized in that it includes a gaseous fuel supply unit for preparing the above diluted gaseous fuel.

As the above gaseous fuel supply unit, those having the following structures are preferred:

(a) a gaseous fuel supply unit, as shown in Fig. 5, including a plurality of gaseous fuel supply pipes disposed along the width direction of the pallet and having slits, openings, or nozzles for ejecting the gaseous fuel; and

(b) a gaseous fuel supply unit, as shown in Fig. 6, including a plurality of gaseous fuel supply pipes disposed along the movement direction of the pallet and having slits, openings, or nozzles for ejecting the gaseous fuel.

In addition, the above gaseous fuel supply unit is preferably capable of controlling the amount of gaseous fuel supplied in the width direction of the pallet by, for example, flow control means provided on the gaseous fuel supply pipes or the nozzles. In particular, the gaseous fuel supply unit is preferably cable of supplying more gaseous fuel near sidewalls in the width direction of the pallet because the gaseous fuel concentration tends to become lower near the sidewalls as the supplied gaseous fuel flows sideward or leaks outside under the influence of crosswinds.

In addition, the above gaseous fuel supply unit needs to dilute the gaseous fuel to a concentration at or below the lower flammable limit concentration thereof by ejecting the gaseous fuel into air above the sintering bed at high speed so as to mix the gaseous fuel with ambient air within a short period of time before introducing the diluted gaseous fuel into the sintering bed.

The reason for diluting the gaseous fuel to a concentration at or below the lower flammable limit concentration will now be described.

Tables 1A and 1B show the lower flammable limit concentrations, supply concentrations, etc. of typical gaseous fuels that can be used for the present invention. In view of preventing a fire, it is safer to supply the gaseous fuel to the sintering raw material in a lower gas concentration as compared to the lower flammable limit concentration. In this regard, town gas, which has a lower flammable limit concentration approximate to that of coke oven gas (C-gas), can be supplied in a lower concentration than C-gas because it has a higher calorific value. Hence, town gas, which can be supplied in a lower concentration, is superior to C-gas in view of ensuring safety. Moreover, as described later, town gas contains no carbon monoxide (CO), which is hazardous to the human body, as its component, and also contains no hydrogen.

Table 1A

Type of gas	CO (vol.%)	H_2 (vol.%)	Calorific value (Mcal/Nm^3)
Town gas	0	0	9.5
C-gas	7	59	4.8
B-gas	24	4	0.8

Table 1B

Type of gas	Source pressure (mmAq)	Maximum amount used (Nm^3/h)	Lower flammable limit concentration (vol.%)	Supply concentration (vol.%)
Town gas	98000	2300	4.8	0.8
C-gas	650	5800	5.0	2.0
B-gas	600	27000	40.0	9.5

Tables 2A and 2B show the types of combustible components (hydrogen, CO, and methane) contained in the gaseous fuel and the lower and upper flammable limit concentrations, laminar and turbulent burning velocities, etc. of these components. To prevent a fire during sintering, that is, a fire due to the gaseous fuel supplied during sintering, a flashback must be avoided. For this purpose, the gaseous fuel may be ejected at a high speed, namely, at least at or above the laminar burning velocity, preferably at or above the turbulent burning velocity. For example, if the gaseous fuel is methane, which is the main combustible component of town gas, there is no risk of a flashback if the gaseous fuel is ejected at a speed exceeding 3.7 m/s. Hydrogen, on the other hand, has a higher turbulent burning velocity than CO and methane and must therefore be ejected at a correspondingly higher speed to ensure safety. In this regard, comparing the gaseous fuels shown in Tables 1A and 1B, town gas, which contains no hydrogen, is advantageous over C-gas, which contains 59% by volume of hydrogen, in that the ejection speed can be lowered. In addition, town gas is safe without the risk of gas poisoning because it contains no CO. Thus, town gas has preferred properties for use as the gaseous fuel in view of ensuring safety. The same also applies to natural gas. C-gas can also be used as the gaseous fuel, although in that case it is necessary to increase the gas ejection speed and to take a measure against CO.

Table 2A

Combustible component	Molecular weight (M)	Combustion heat (kcal/g)	Theoretical mixture proportion (Fuel vol.%)
Hydrogen	2.0	28.62	29.5
CO	28.0	2.406	29.5
Methane	16.0	11.93	9.47

Table 2B

	Flammable limit concentration (vol.%)		Ignition temperature (°C)	Laminar burning velocity		Turbulent burning velocity Maximum (m/s)
	Lower limit	Upper limit		Maximum (cm/s)	Equivalence ratio (ϕ)	
Hydrogen	4.0	75	571	291	1.70	29.1
CO	12.5	74	609	43	1.70	4.3
Methane	5.0	15.0	632	37	1.06	3.7

Table 3 shows the evaluation results of methods for supplying a gaseous fuel for advantages and disadvantages. In the table, direct injection refers to a method in which a gaseous fuel, such as town gas or C-gas, is diluted to a predetermined concentration by directly supplying (ejecting) it so as to draw ambient air therein and is sucked (introduced) into the sintering bed, whereas premix injection refers to a method in which a gaseous fuel diluted to a predetermined concentration by mixing it with air in advance is supplied to the sintering bed and is sucked (introduced) into the sintering bed. In direct injection, a flashback can be easily avoided by ejecting the gaseous fuel at or above the turbulent burning velocity described above; in premix injection, a flashback can be caused by a concentration deviation. On the other hand, direct injection has a higher possibility of abnormal combustion than premix injection because a concentration variation occurs easily when the gaseous fuel is diluted by mixing it with ambient air. Nevertheless, direct injection with town gas is most advantageous when evaluated as a whole, including equipment costs.

Table 3

Injection method	Type of gas	Flashback	Problems due to gas retention			Construction cost		Comprehensive evaluation
			Abnormal combustion	Poisoning	Oxygen deficiency	Pipe diameter	Accessory equipment	
Direct injection	Town gas	A	B	A	C	Small	Little	First
	C-gas	A	B	C	C	Medium	Little	Second
Premix injection	Town gas	C	A	A	C	Large	Much	Third
	C-gas	C	A	C	C	Large	Much	Fourth

In the present invention, additionally, the above gaseous fuel supply unit needs to dilute the gaseous fuel to a concentration at or below the lower flammable limit concentration thereof by ejecting the gaseous fuel into air above the sintering bed at high speed so as to mix the gaseous fuel with ambient air within a short period of time before introducing the diluted gaseous fuel into the sintering bed. The reason will be described below.

Fig. 7 shows diagrams illustrating an experiment for examining the effect of the position where the gaseous fuel is supplied on sinter cake. As shown in Fig. 7(a), sinter cake was charged into a sinter pot having an inner diameter of 300 mm and a height of 400 mm, and a nozzle was embedded to a depth of 90 mm from the top in the center of the sinter cake. A 100% methane gas was injected in a concentration of 1% by volume based on the volume of air, and the methane gas concentration of the sinter cake was measured in the circumferential direction and the depth direction. The measurement results are shown in Table 4. As shown in Fig. 7(b), on the other hand, the same nozzle was used to supply methane gas from a position 350 mm above the sinter cake, and the methane gas concentration distribution was measured in the same manner as above. The measurement results are shown in Table 5. These results demonstrate that the methane gas diffused insufficiently in the transverse direction when the methane gas was directly introduced into the sinter cake, whereas the methane gas concentration of the sinter cake was substantially uniform, that is, the methane gas diffused sufficiently in the transverse direction, when the methane gas was supplied above the sinter cake. According to the above results, it is preferable to supply the gaseous fuel to air above the sinter cake to uniformly dilute the gaseous fuel before introducing it into the sintering bed.

Table 4

Distance from center (mm)		0		40		80		122.5	
Injection nozzle		Straight		Straight		Straight		Straight	
Injection method		Embedded in cake		Embedded in cake		Embedded in cake		Embedded in cake	
Volume of air (m^3/min)		1.5	2.0	1.5	2.0	1.5	2.0	1.5	2.0
Air speed (m/s)		0.35	0.47	0.35	0.47	0.35	0.47	0.35	0.47
Depth of injection (mm)		-90	-90	-90	-90	-90	-90	-90	-90
Methane gas concentration (%)	Position 100 mm from surface	Measuring probe melted		0.05	0.05	0.00	0.00	0.00	0.00
	Position 150 mm from surface	>10.23	>10.23	1.12	1.24	0.00	0.00	0.00	0.00
	Position 200 mm from surface	6.83	7.15	1.12	1.13	0.01	0.01	0.00	0.00
	Position 250 mm from surface	3.24	3.28	0.83	0.88	0.13	0.13	0.04	0.02
	Position 300 mm from surface	3.09	3.21	2.69	2.81	0.94	0.91	0.08	0.07
	Position 350 mm from surface	2.93	3.02	1.68	1.74	1.31	1.31	0.23	0.25
	In wind box	0.85	0.83	0.88	0.85	0.86	0.84	0.82	0.83

A methane gas concentration of 10.23% or more could not be measured.

Table 5

Distance from center (mm)		0		40		80		122.5	
Injection nozzle		Straight		Straight		Straight		Straight	
Injection method		Injected from above cake		Injected from above cake		Injected from above cake		Injected from above cake	
Volume of air (m^3/min)		1.5	2.0	1.5	2.0	1.5	2.0	1.5	2.0
Air speed (m/s)		0.35	0.47	0.35	0.47	0.35	0.47	0.35	0.47
Depth of injection (mm)		350	350	350	350	350	350	350	350
Methane gas concentration (%)	Position 100 mm from surface	Measuring probe melted		1.73	1.76	1.66	1.66	1.50	1.67
	Position 150 mm from surface	1.66	1.83	1.90	1.96	1.49	1.42	1.38	1.31
	Position 200 mm from surface	1.63	1.66	1.55	1.54	1.40	1.29	1.36	1.20
	Position 250 mm from surface	1.57	1.58	1.28	1.29	1.45	1.41	1.26	1.34
	Position 300 mm from surface	1.32	1.33	1.31	1.37	1.45	1.41	1.39	1.43
	Position 350 mm from surface	1.20	1.23	1.21	1.27	1.33	1.29	1.48	1.39
	In wind box	0.84	0.85	0.86	0.85	0.83	0.82	0.83	0.84

A methane gas concentration of 10.23% or more could not be measured.

Next, the gaseous fuel is preferably ejected at high speed from the outlets, such as slits or nozzles, provided in the gaseous fuel supply pipes of the gaseous fuel supply unit in view of avoiding a flashback. That is, in the sintering operation of the present invention, the gaseous fuel, which is diluted to a concentration at or below the lower flammable limit concentration before being sucked and introduced into the surface layer of the sintering bed, is supplied from above the sintering bed while the sinter pallet carries an ignition source, that is, a sintering bed in which the combustion and melting zone is to be formed or is being formed. Therefore, if the gaseous fuel is ejected at low flow speed from the outlets, such as nozzles, some ignition source might ignite the gaseous fuel supplied from the gaseous fuel supply unit to cause a flashback, thus leading to explosion and combustion in the gaseous fuel supply unit or the gaseous fuel supply pipes. Accordingly, the gaseous fuel is preferably ejected at a speed twice or more the burning velocity of the gaseous fuel, more preferably twice or more the turbulent burning velocity of the gaseous fuel, so that no flashback occurs in the event of ignition of the gaseous fuel. For example, methane gas has a laminar burning velocity of about 0.4 m/s and a turbulent burning velocity of about 4 m/s.

Accordingly, an experiment for examining the conditions where a blow-off actually occurs at the above burning velocity was conducted.

In this experiment, outlets having opening diameters of 1, 2, and 3 mm were formed in 25A pipes. LNG gas was supplied to the pipes so as to be ejected from the outlets and was ignited using an ignition source. Subsequently, the ejection speed at which a blow-off occurred when the ignition source was separated was measured. Here, the above ejection speed was controlled by changing the header pressure of the LNG gas.

As a result, it was found that if the opening diameter of the outlets is 1 mm, a blow-off occurs if the header pressure of the LNG gas is 300 mmH_2O or more and the ejection speed of the gaseous fuel is 70 m/s or more, and that if the opening diameter is 2 mm, a blow-off occurs if the header pressure of the LNG gas is 550 mmH_2O or more and the ejection speed of the gaseous fuel is 130 m/s or more. On the other hand, for an opening diameter of 3 mm, the gaseous fuel could be prevented from burning at the outlets by ejecting the gaseous fuel at a supersonic speed with the header pressure of the LNG gas raised to 2,000 mmH_2O, although the gaseous fuel burned in the downstream low-speed region, which is called lifting, and the fire could not be reliably blown off.

As described above, it was found that if LNG gas or a fuel gas having a burning velocity equivalent to that of LNG gas (such as methane, ethane, or propane gas) is used, an opening diameter of less than 3 mm is preferred to prevent a flashback by causing a blow-off. In addition, although the gaseous fuel can be prevented from burning at the outlets simply by ejecting the gaseous fuel at or above the burning velocity, it cannot be prevented from burning in the downstream low-speed region (lifting). In the present invention, therefore, the gaseous fuel is ejected from the outlets at or above the speed at which a blow-off occurs to prevent lifting. To cause a blow-off, the gaseous fuel is preferably ejected at high speed from gas outlets having an opening diameter of less than 3 mm, for example, at a speed of 70 m/s or more if the opening diameter is equivalent to 1 mm, at a speed of 100 m/s or more if the opening diameter is equivalent to 1.5 mm, and at a speed of 130 m/s or more if the opening diameter is 2 mm.

If the present invention is applied to an actual machine, the opening diameter preferably falls within the range of 0.5 to 1.5 mm. If the opening diameter falls below 0.5 mm, such openings are difficult to form in pipes and are also easily clogged with, for example, dust contained in the gas. On the other hand, if the opening diameter exceeds 1.5 mm, a relatively high ejection speed is required to cause a blow-off; a lower ejection speed is preferred to ensure safety.

Although the size of the outlets is specified in terms of the diameter of circular outlets in the above description, the outlets may have any other shape having the same opening area, such as oval outlets or elongated outlets (slits).

In addition, because the ejection speed of the gaseous fuel varies not only with the opening diameter, but also with the supply pressure of the gaseous fuel, it may be controlled on the basis of the relationship between the pressure and flow speed (ejection speed) of the nozzles forming the openings to attain an ejection speed at which a blow-off occurs. The relationship between the nozzle pressure and the nozzle flow speed is represented by the following equation:

$$\Delta P = \rho \cdot V^2/(2 \cdot g)$$

where ΔP is the difference in nozzle pressure (mmH_2O), ρ is the density (kg/m^3) of the gaseous fuel at 30°C, V is the nozzle flow speed (m/s), and g is the gravitational acceleration (m/s^2). This can be used to determine the nozzle flow speed.

In addition, if LNG gas is ejected from orifices having an opening diameter of 1 mm, a blow-off can be caused by ejecting the gas at a speed of 70 m/s for a nozzle pressure of 300 mmH_2O. If LNG gas is ejected from orifices having an opening diameter of 1.5 mm, a blow-off can be caused by ejecting the gas at a speed of 100 m/s for a nozzle pressure of 700 mmH_2O.

To attain the above ejection speed of the gaseous fuel, the pressure of the gaseous fuel ejected from the nozzles, openings, or slits is preferably 300 mmAq to less than 40,000 mmAq with respect to the ambient pressure.

In general, if the pipes for ejecting the gaseous fuel have the same shape as the openings, more fuel is ejected at a position closer to the supply header, and less fuel is ejected at a position farther away from the supply header. Accordingly, if elongated pipes are used, the fuel can be uniformly supplied despite their large pipe length by applying one or a combination of the following techniques:

(a) using tapered pipes in which the cross-sectional area decreases gradually;

(b) increasing the cross-sectional area of the openings farther away from the fuel supply header; and

(c) decreasing the pitch of the openings or nozzles farther away from the fuel supply header so that the sum of the cross-sectional areas of the openings or nozzles per unit pipe length is increased.

As for the direction in which the gaseous fuel is ejected into air, any of the following methods can be employed:

(a) As shown in Fig. 8, the gaseous fuel is ejected downward toward the sintering bed (vertically downward) so that a portion thereof is reflected and diluted;

(b) As shown in Fig. 9, the gaseous fuel is ejected in parallel with the surface of the sintering bed (horizontally) to extend the path along which the gaseous fuel is introduced into the sintering bed, thus facilitating dilution;

(c) As shown in Fig. 10, the gaseous fuel is ejected toward and reflected off baffle plates (reflective plates), thus facilitating dilution;

(d) As shown in Fig. 11, the gas ejection slits, openings, or nozzles provided in the gaseous fuel supply pipes are directed toward the surface of the sintering bed so as to diverge in multiple directions within the range of ±90° with respect to the perpendicular direction, thus facilitating dilution; and

(e) As a variant of Fig. 11, the gaseous fuel supply pipes are rotatable about the axes thereof so that the ejections directions thereof can be rotated.

The above gaseous fuel supply unit preferably ejects the gaseous fuel at a height of 300 mm or more above the surface of the sintering bed. Fig. 12 shows the measurement results of spreads of methane gas (concentration: 100%) ejected vertically downward from two types of nozzles having nozzle diameters of 2 mm and 1 mm at flow speeds varying in the range of 20 to 300 m/s. Fig. 12 shows spreads of methane gas at positions 0.2 m, 0.4 m, 0.6 m, and 0.8 m from the tips of the nozzles. As shown in Fig. 12, the gaseous fuel is more smoothly mixed and diluted with ambient air as the nozzle diameter becomes smaller and the ejection speed of the gaseous fuel becomes higher, and particularly, the effect of facilitating dilution by increasing the speed is increased at a distance from the tips of the nozzles of 0.4 m. In the present invention, therefore, taking into account these results and the bouncing of the ejected gaseous fuel off the surface of the sintering bed, the gaseous fuel is preferably supplied to air at a height of 300 mm or more above the surface of the sintering bed.

In addition, as described above, a higher ejection speed is preferred because the gaseous fuel is more smoothly mixed and diluted with ambient air as the ejection speed of the gaseous fuel becomes higher. Furthermore, if the gaseous fuel is ejected at low flow speed from the outlets, such as nozzles, some ignition source might ignite the gaseous fuel supplied from the gaseous fuel supply unit to cause a flashback, thus leading to explosion and combustion in the gaseous fuel supply unit or the gaseous fuel supply pipes. To avoid this risk, the gaseous fuel is preferably ejected at a speed twice or more the burning velocity of the gaseous fuel used, more preferably twice or more the turbulent burning velocity of the gaseous fuel. For example, methane gas has a laminar burning velocity of about 0.4 m/s and a turbulent burning velocity of about 4 m/s.

Next, measures against crosswinds for the gaseous fuel supply unit of the present invention will be described.

The gaseous fuel supplied from the gaseous fuel supply unit to air above the sintering bed is diluted and sucked through the wind boxes disposed below the pallet. Although all the gaseous fuel is normally introduced into the sintering bed together with ambient air, the supplied gaseous fuel may flow sideward when blown by a crosswind laterally with respect to the movement direction of the pallet, particularly, as the wind speed becomes higher. Fig. 13 shows the results of an analysis of the influence of crosswinds on the concentration distribution of the gaseous fuel at wind speeds of 2 m/s and 5 m/s. These results demonstrate that if no measured is taken, even a crosswind at a wind speed of 2 m/s dissipates the gaseous fuel and adversely influences the concentration distribution of the gaseous fuel introduced into the sintering bed.

Accordingly, to reduce the influence of crosswinds, the effect of 2 m high partitions disposed on both sides of the gaseous fuel supply unit was analyzed at a wind speed of 5 m/s, and the results are shown in Fig. 14. Fig. 14(a), which shows the results of the case where the 2 m high partitions were disposed, revealed that the partitions did not provide a sufficient effect because a swirling occurred inside the partitions and dissipated the gaseous fuel at a wind speed of 5 m/s. On the other hand, Fig. 14(b), which shows the results of the case where the portions extending 1 m from the tops of the 2 m high partitions were formed of a material having a void rate of 30%, revealed that the voids inhibited swirling of air and prevented dissipation of the gaseous fuel.

The above analytical results demonstrate that it is effective to dispose members having a partitioning effect against crosswinds on both sides of the gaseous fuel supply unit to prevent dissipation of the gaseous fuel by crosswinds and that swirling due to the partitions can be reduced by providing voids in the partitions in an area percentage of about 30%.

The present inventors further studied the reduction of the influence of crosswinds by providing a hood above the gaseous fuel supply unit. As a result, it was found that a hood provides a greater effect as a measure against crosswinds than partitions. This hood, however, is preferably configured to have an opening or appropriate permeability (void rate) in the center of the top portion so that air can be taken in through that portion. This allows air to be mixed with the gaseous fuel ejected from the gaseous fuel supply pipes to prepare a diluted gaseous fuel inside the hood. For a sintering machine having a pallet width of 5 m, the pressure loss due to the hood is substantially negligible if the opening portion has a width of about 1 m. In addition, it was found that if voids are provided in the opening portion, the pressure loss can be reduced to several mmAq if the permeability is about 80%. Furthermore, the analytical results revealed that straightening vanes disposed inside the hood have the effect of inhibiting swirling in the hood and that the most effective void rate of partitions disposed on the top (periphery) of the hood is 30% to 40%.

In addition, it was found that a gap is inevitably left between the bottom end of the hood and the surface of the sintering bed and, if the gap is insufficiently sealed, for example, if the permeability is 20% to 30%, air is drawn into the hood through that portion, thus increasing unevenness in the concentration distribution of the gaseous fuel. Accordingly, it is important to prevent intrusion of air through the bottom end of the hood, and it is preferable to dispose, for example, seals such as chain curtains, wire-plate seals, or brush seals or contact seals, as shown in Fig. 15, or air curtains, as shown in Fig. 16, between the bottom end of the hood and the surface of the sintering bed or between the bottom end of the hood and the sidewalls of the pallet. The above seals are preferably heat-resistant, highly flexible or deformable, and are nonabrasive to the surface of the sintering bed.

The results of an analysis of the effect of the above hood in the case where a crosswind blows at 5 m/s using a computational fluid analysis code based on the finite volume method will now be described. Fig. 17 shows a gaseous fuel supply unit used for calculation and a hood disposed thereabove. The pallet width of the sintering machine was 5 m. Gas injection pipes for ejecting a gaseous fuel were arranged in parallel with the movement direction of the pallet at intervals of 600 mm at a height of 500 mm above the sintering bed (sintering bed), straightening vanes were disposed on and above the gas injection pipes, and the food was disposed thereabove. An opening having a width of 1,000 mm (the void rates for calculation were 100% and 80%) was provided in the center of the top portion. In addition, fences for attenuating crosswinds having a permeability of 30% were provided above the side of the hood. The permeability at the bottom end of the hood was set to 20% on the assumption that chain curtains were provided.

Fig. 18 shows the analytical results of the concentration distribution of the gaseous fuel. These results demonstrate that the concentration distribution of the gaseous fuel is improved if the top portions of the sidewalls of the hood are inclined so as to narrow the top portion of the hood, that the difference between the case where the void rate of the opening is 100% and the case where the void rate of the opening is 80% is small, and that swirling is inhibited by the straightening vanes. Fig. 19 shows the analytical results of pressure distribution, demonstrating that the pressure loss due to the inclined top portion of the hood is small and that swirling is inhibited by the straightening vanes. Fig. 20 shows the analytical results of gas flow velocity distribution, demonstrating that a drift is caused by an inflow of air if the bottom end of the hood is permeable. In addition, Fig. 21 shows a vector diagram of the gas flow velocity, demonstrating that swirling is inhibited by the inclined top portion of the hood and the straightening vanes.

In addition, as shown in all of Figs. 18 to 21, even if the hood is disposed, there is a difference in the amount of air drawn between the upwind and downwind sides, and another measure must be taken to solve this problem. As this measure, it is effective to eject different amounts of gaseous fuel on the upstream and downstream sides or to narrow the top portion of the hood more than in the above calculation model.

Next, based on the above findings, examples of the application of the measures against crosswinds to a gaseous fuel supply unit of an actual sintering machine will be described. Fig. 22 shows an example in which a hood having an opening in the top portion thereof is disposed above the gas supply unit, fences for preventing swirling having a permeability of 30% are disposed thereabove, chain curtains (wire-plate seals) for preventing intrusion of crosswinds through the gaps between the hood and the pallet are suspended from the bottom end of the hood, and straightening vanes are disposed on the gas injection pipes located at both ends. Fig. 23, a modification of Fig. 22 above, shows an example in which straightening vanes are disposed along the gaseous fuel supply pipes in the hood. In addition, Fig. 24 shows an example in which the top portion of the hood in Fig. 23 above is open and straightening vanes are disposed instead. It is preferable to appropriately change the intervals at which the above straightening vanes are arranged. In addition, Fig. 25 shows an example in which the top portion of the hood in Fig. 24 is completely open and only straightening vanes are disposed in the top portion, and Fig. 26 shows an example in which straightening vanes and baffle plates for facilitating the mixing of the gaseous fuel are used in combination in the hood. All the hoods shown above have the effect of reducing the influence of crosswinds.

In the present invention, additionally, the gaseous fuel is preferably used as a diluted gaseous fuel by diluting it so that the concentration of the combustible component contained in the flammable gas is 75% or less of the lower flammable limit concentration, more preferably 60% or less of the lower flammable limit concentration, and further preferably 25% or less of the lower flammable limit concentration, at normal temperature in air. The flammable gas diluted to a concentration of 75% or less of the lower flammable limit concentration or less is used for the following two reasons:

(a) It is necessary to supply the flammable gas to the upper portion of the sintering bed such that it does not burn despite the presence of an ignition source at least at normal temperature because directly supplying the flammable gas occasionally leads to explosive combustion; and

(b) It is necessary to avoid the risk of the flammable gas burning due to discharging of, for example, an electrostatic precipitator downstream of the wind boxes even if the gas reaches the electrostatic precipitator while remaining unburned without being completely combusted in the sintering bed.

In addition, as described later, the gaseous fuel must be diluted to such an extent as not to cause insufficient combustion due to a deficiency of air (oxygen) required for combustion of all carbonaceous material in the sintering raw material (solid and gaseous fuels).

On the other hand, the concentration of the diluted gaseous fuel is preferably 2% or more of the lower flammable limit concentration. If the concentration falls below 2%, the heat generated by combustion is insufficient to improve the strength and yield of sintered ore. In addition, the concentration of the diluted gaseous fuel is preferably adjusted depending on the amount of carbonaceous material (solid fuel). Furthermore, the diluted gaseous fuel can be combusted at a particular position in the sintering bed by adjusting the concentration thereof.

In the method for producing sintered ore according to the present invention, the diluted gaseous fuel is preferably supplied (introduced) to the sintering bed after the ignition of the carbonaceous material in the sintering bed. The reason is that if the diluted gaseous fuel is supplied to the position immediately after the ignition, it burns only above the surface layer of the sintering bed and has no effect on the sintering bed. Accordingly, the diluted gaseous fuel is preferably supplied to the sintering bed after the sintering raw material in the upper portion of the sintering bed is fired to form a layer of sinter cake. The diluted gaseous fuel can be supplied at any position before burn-through as long as a layer of sinter cake has been formed on the surface of the sintering bed. Other reasons for supplying the diluted gaseous fuel after the formation of a layer of sinter cake are as follows:

(a) If the diluted gaseous fuel is supplied before sinter cake is formed in the upper portion of the sintering bed, it can cause explosive combustion above the sintering bed; and

(b) It is preferable to supply the diluted gaseous fuel to a portion where the yield of sintered ore needs to be improved, that is, so as to cause combustion in a portion where the strength of sintered ore should be improved.

To adjust one or both of the ultimate maximum temperature and the high-temperature-zone holding time in the sintering bed, the diluted gaseous fuel is preferably supplied after the thickness of the combustion and melting zone reaches at least 15 mm or more, preferably 20 mm or more, and more preferably 30 mm or more. If the thickness of the combustion and melting zone falls below 15 mm, the thickness of the combustion and melting zone cannot be increased because the combustion of the gaseous fuel has an insufficient effect under the cooling effect of the air and diluted gaseous fuel sucked through the sintering bed (sinter cake). On the other hand, if the diluted gaseous fuel is supplied after the thickness of the combustion and melting zone reaches 15 mm or more, preferably 20 mm or more, and more preferably 30 mm or more, the thickness of the combustion and melting zone increases significantly so that the high-temperature-zone holding time can be extended, thus providing a sintered ore with high cold strength.

The thickness of the combustion and melting zone can be examined using, for example, a vertical cylindrical test pot with a transparent quartz window. This test pot is effective means for determining the position where the diluted gaseous fuel is supplied.

In addition, the diluted gaseous fuel is preferably introduced into the sintering bed at a position where the combustion front has propagated below the surface and the combustion and melting zone has propagated 100 mm or more, more preferably 200 mm or more, downward from the surface, that is, to the middle or lower layer region. In other words, the diluted gaseous fuel is preferably supplied so that it passes, without burning, through the sinter cake region (sintering bed) generated in the surface layer of the sintering bed and burns after the combustion front propagates 50 mm or more from the surface. The reason is that the adverse effect of cooling due to air sucked through the sintering bed can be reduced at a position where the combustion front has propagated 100 mm or more downward from the surface so that the thickness of the combustion and melting zone can be increased. Furthermore, the effect of cooling due to air can be substantially eliminated at a position where the combustion front has propagated 200 mm or more downward from the surface so that the thickness of the combustion and melting zone can be increased to 30 mm or more. In addition, the diluted gaseous fuel is more preferably supplied near the sidewalls on both sides of the pallet in the width direction thereof, where the yield is lower.

For example, the diluted gaseous fuel generation unit is preferably disposed at a position about 5 m or more downstream of the ignition furnace for a sintering machine having a gaseous fuel supply capacity of 1,000 to 5,000 m^3(standard)/h, a production capacity of about 15,000 t/day, and a length of 90 m, although the position depends on the size of the sintering machine.

In the production apparatus according to the present invention, the diluted gaseous fuel is preferably supplied (introduced into the sintering bed) at any one or more positions downstream of the ignition furnace in the movement direction of the pallet between a position where the combustion front has propagated below the surface after the formation of sinter cake (for example, a position 100 mm or more, preferably about 200 mm or more, below the surface where the combustion of the gaseous fuel occurs) and a burn-through position. As described above, this means that the introduction of the gaseous fuel is started after the combustion front propagates below the surface of the sintering bed, and accordingly means that a safe sintering operation is permitted without the risk of explosion because the combustion of the gaseous fuel occurs inside the sintering bed and propagates gradually downward.

In the production method according to the present invention, the introduction of the diluted gaseous fuel into the sintering bed also means that reheating of the resultant sinter cake is facilitated. That is, the diluted gaseous fuel, which is more reactive than the solid fuel, is supplied to a portion where the cold strength of sintered ore tends to be lower because of insufficient heat due to a short high-temperature-zone holding time, to supplement the combustion heat in that portion with insufficient heat, thus playing a role in regeneration and broadening of the combustion and melting zone.

In the method for producing sintered ore according to the present invention, additionally, the diluted gaseous fuel is preferably supplied from above the sintering bed after the ignition so that at least a portion of the diluted gaseous fuel introduced into the sintering bed reaches the combustion and melting zone while remaining unburned, thus burning at a position where the combustion heat should be supplemented. The reason is that it is more effective to spread the effect of supplying the diluted gaseous fuel, that is, introducing it into the sintering bed, beyond the upper portion of the sintering bed to the central portion in the thickness direction, namely, the combustion and melting zone. In other words, if the gaseous fuel is supplied to the upper layer of the sintering bed, which tends to have insufficient heat (insufficient high-temperature-zone holding time), sufficient combustion heat can be supplied to improve the quality of sinter cake in that portion. In addition, if the effect of supplying the diluted gaseous fuel is spread to the middle and lower layers, the result is equivalent to the formation of a recombustion and remelting zone by the diluted gaseous fuel above the original combustion and melting zone formed by the carbonaceous material, thus broadening the combustion and melting zone in the vertical direction. Thus, the high-temperature-zone holding time can be extended without raising the ultimate maximum temperature so that sufficient sintering can be achieved without decreasing the movement speed of the pallet. This improves the quality (cold strength) of sinter cake in the entire sintering bed and therefore improves the quality (cold strength) and productivity of sintered ore products.

A first characteristic of the present invention lies in that the position where the diluted gaseous fuel is supplied is determined in view of where to apply the effect of supplying the diluted gaseous fuel in the sintering bed. A second characteristic lies in to which levels to control the ultimate maximum temperature and the high-temperature-zone holding time in the sintering bed depending on the amount of solid fuel with the calorific value remaining constant while supplying the fuel.

In the present invention, therefore, it is preferable not only to adjust the position where the diluted gaseous fuel is supplied (introduced) to the sintering bed, but also to control the form of the combustion and melting zone itself and therefore to control the ultimate maximum temperature and/or the high-temperature-zone holding time in the combustion and melting zone.

In general, in a sintering bed after ignition, the position of the combustion and melting zone changes as shown in Fig. 4(a) while the combustion (flame) front propagates gradually downward and frontward (downstream) as the pallet is moved. As shown in Fig. 4(b), the thermal history of the sintering bed during the sintering process differs between the upper, middle, and lower layers, and the high-temperature-zone holding time (time during which the temperature is about 1,200°C or more) differs significantly between the upper to lower layers. As a result, the yields of sintered ore at different positions in the pallet have the distribution shown in Fig. 4(c). Specifically, the yield is lower in the surface layer (upper layer) and is higher in the middle and lower layers. Therefore, if the gaseous fuel is supplied according to the method of the present invention, the combustion and melting zone is broadened, for example, across the thickness in the vertical direction and the width in the movement direction of the pallet, thus leading to an improvement in the quality of sintered ore products. In addition, the high-temperature-zone holding time can also be controlled in the middle and lower layers, where the yield is higher, so that the yield can be further improved.

By adjusting the position where the gaseous fuel is supplied (introduced), it is possible to control the form of the combustion and melting zone, that is, the thickness of the combustion and melting zone in the height direction and/or the width in the movement direction of the pallet, and also to control the ultimate maximum temperature and the high-temperature-zone holding time. Such control, enhancing the advantages of the present invention, allows constantly sufficient firing by broadening the combustion and melting zone across the thickness in the vertical direction and the width in the movement direction of the pallet and controlling the ultimate maximum temperature and the high-temperature-zone holding time, thus effectively contributing to an improvement in the cold strength of sintered ore products.

In other words, the supply (introduction) of the diluted gaseous fuel to the sintering bed in the present invention is intended to control the cold strength of sintered ore products as a whole. That is, the original object of supplying the diluted gaseous fuel is to improve the cold strength of sinter cake and therefore the cold strength of sintered ore, particularly, to achieve a cold strength (shutter index SI) of sintered ore of about 75% to 85%, preferably 80% or more, and more preferably 90% or more, by controlling the position where the gaseous fuel is supplied, the high-temperature-zone holding time, which is the time during which the sintering raw material remains in the combustion and melting zone, and the ultimate maximum temperature.

This strength level can be achieved at low cost in the present invention by adjusting, particularly, the concentration, amount, position, and range where the diluted gaseous fuel is supplied, preferably taking into account the amount of carbonaceous material in the sintering raw material (with the calorific value supplied remaining constant). Improving the cold strength of sintered ore may involve increased airflow resistance and therefore decreased productivity. The present invention solves that problem by controlling the ultimate maximum temperature and the high-temperature-zone holding time while improving the cold strength of sintered ore. The cold strength, SI, of a sintered ore produced by an actual sintering machine is 10% to 15% higher than the value obtained by a pot test.

In the production method of the present invention, the position where the diluted gaseous fuel is introduced into the sintering bed in the movement direction of the pallet is controlled on the basis of the intended cold strength of sintered ore in any region between the sinter cake formed in the sintering bed and the wet zone. For this control, in the present invention, the scale (size), number, positions (distances from the ignition furnace), and gas concentration of gaseous fuel supply units are adjusted, preferably depending on the amount of carbonaceous material (solid fuel) in the sintering raw material, not only to control the size of the combustion and melting zone (the thickness in the vertical direction and the width in the movement direction of the pallet), but also to control the high temperature reached and the high-temperature-zone holding time, thereby controlling the strength of the sinter cake formed in the sintering bed.

In the above production method of the present invention, the gaseous fuel supplied to the sintering bed is preferably one of blast furnace gas, coke oven gas, a mixture of blast furnace gas and coke oven gas, town gas, natural gas, methane gas, ethane gas, propane gas, butane gas, and a mixture thereof. One of these gaseous fuels, all of which contain a combustible component, is ejected into air at high speed so as to be mixed and diluted with air and is supplied (introduced) to the sintering bed as a diluted gaseous fuel in a concentration of about 75% or less of the lower flammable limit concentration.

In the present invention, in addition to the above gaseous fuels, vapors of liquid fuels having an ignition temperature in vapor phase higher than the temperature of the surface layer of the sintering bed can also be used as the gaseous fuel supplied to the sintering bed, including alcohols, ethers, petroleum oils, and other hydrocarbon compounds. Table 6 shows types and properties of liquid fuels that can be used in the present invention. Such a vaporized liquid fuel is effective in broadening the marginal temperature range of the combustion and melting zone at the injection position because it has a higher ignition temperature than the gaseous fuels described above and therefore burns in a deeper region of the sintering bed at a higher temperature than the surface layer of the sintering bed. In particular, a vaporized liquid fuel having an ignition temperature close to 500°C is highly effective. If a vaporized liquid fuel is used, the gas supply pipes are preferably maintained at a temperature of not less than the boiling point of the liquid fuel and less than the ignition temperature thereof so that the vaporized fuel does not reliquefy.

Table 6

Name of material (liquid fuel)	Specific gravity (15°C)	Boiling point (°C)	Flammable limit (vol%)		Ignition temperature (°C)
			Lower limit	Upper limit	
Pentane	0.631	36.0	1.5	7.8	284
Hexane	0.664	68.7	1.2	7.4	260
Heptane	0.688	98.4	1.2	6.7	247
Octane	0.707	125.0	1.0	-	240
Nonane	0.722	150.0	0.8	2.9	234
Decane	0.734	174	0.8	5.4	231
Benzene	0.885	80.1	1.3	7.9	592
Acetone	0.792	56.6	2.6	13	561
Methyl alcohol	0.793	64.4	6.7	36	470
Ethyl alcohol	0.789	78.3	3.3	19	392
Diethyl ether	0.714	34.4	1.9	48	185
Kerosene	0.8 to 0.85	160 to 320	1.1	6.0	255
Diesel oil	0.83 to 0.88	250 to 350	1.0	6.0	250

Waste oil, for example, is not preferred for use in the present invention because it sometimes contains an easily flammable component or a component having a low ignition temperature. If a liquid fuel, such as waste oil, containing a component having a low ignition temperature or flashpoint is vaporized in advance and is supplied to the sintering raw material bed, the effect, intended by the present invention, of extending the high-temperature holding time by combusting the gaseous fuel near the combustion zone of the sintering raw material bed cannot be achieved because the liquid fuel burns in the space above the surface layer of the mix bed or near the surface layer of the mix bed before reaching the combustion zone in the mix bed.

In the present invention, additionally, of the above gaseous fuels, those having a CO content of 50 ppm by mass or less are preferably used. This is because CO gas is hazardous to the human body and might cause a man-made disaster if the gaseous fuel supplied to the sintering bed leaks from the machine without all being introduced into the sintering bed. Specifically, the use of town gas 13A or propane gas is more preferable in view of safety and cost.

In addition, sintered ore is produced by the method of the present invention using a sintering machine including a circulating pallet, a mix supply unit for charging a sintering raw material containing ore fines and a carbonaceous material onto the pallet to form a sintering bed, an ignition furnace for igniting the carbonaceous material in the sintering raw material, a wind box disposed below the pallet, and a gaseous fuel supply unit, disposed downstream of the ignition furnace, for introducing a gaseous fuel into the sintering bed by supplying the gaseous fuel to air above the sintering bed so as to dilute the gaseous fuel to a concentration at or below a lower flammable limit concentration.

The gaseous fuel supply unit of the sintering machine of the present invention is preferably disposed so as to straddle both sidewalls of the pallet along the width direction of the sintering machine. The gaseous fuel supply unit includes a plurality of, preferably three to fifteen, gaseous fuel supply pipes disposed in a direction parallel or perpendicular to the movement direction of the pallet. Preferably, each pipe has a plurality of slits, outlets, or nozzles for supplying the gaseous fuel to air at high speed.

At least one gaseous fuel supply unit is disposed at any position downstream of the ignition furnace in the movement direction of the pallet in the process in which the combustion and melting zone propagates through the sintering bed. The gaseous fuel is preferably supplied to the sintering bed after the ignition of the carbonaceous material in the sintering bed. That is, at least one unit is disposed at any position downstream of the ignition furnace where the combustion front has propagated below the surface, and the size, positions, and number of units are determined in view of adjusting the target cold strength of sintered ore products. In addition, the gaseous fuel supply unit is preferably disposed at low-yield portions near both sidewalls. The gaseous fuel used is preferably a flammable gas diluted to a concentration of 75% to 2% of the lower flammable limit concentration, 60% to 2% of the lower flammable limit concentration, or 25% to 2% of the lower flammable limit concentration.

Fig. 27 shows an embodiment of the apparatus for producing sintered ore according to the present invention, although the present invention is not limited to this exemplary embodiment. Disposed in the example shown in Fig. 27 is a single gaseous fuel supply unit 12 for ejecting a gaseous fuel, such as a mixture of blast furnace gas and coke oven gas (M-gas), into air above a sintering bed downstream of an ignition furnace 10 in the movement direction of a pallet so as to dilute the gaseous fuel to the intended concentration. The gaseous fuel supply unit 12 includes a plurality of gaseous fuel supply pipes 12a disposed along the width direction of the pallet and a plurality of nozzles 12b, for ejecting the gaseous fuel into air at high speed, disposed on the pipes downward and along the width direction of the pallet so as to cover the sintering bed above the sidewalls (not shown). The M-gas supplied from the gaseous fuel supply unit 12 is mixed with ambient air as a diluted gaseous fuel and is then introduced from above the sintering bed into the deep portion (lower layer) of the sintering bed through the sinter cake formed in the surface layer by means of suction through wind boxes (not shown) below the pallet 8. The gaseous fuel supply unit 12 preferably has the nozzles 12a concentrated near both sidewalls of the pallet to supply more gaseous fuel there, particularly for improving the yield on both sides of the pallet (regions with a yield of 60% in Fig. 4(c)).

Examples of the gaseous fuel supplied from the gaseous fuel supply unit 12 include blast furnace gas (B-gas), coke oven gas (C-gas), a mixture of blast furnace gas and coke oven gas (M-gas), town gas, natural gas (LNG), methane gas, ethane gas, propane gas, butane gas, and mixtures thereof. These gaseous fuels may be supplied either from piping independent of the ignition furnace 10 or from the same type of fuel pipe as that for the ignition furnace 10, that is, from a pipe connected to an extension of a gas supply pipe (not shown) for the ignition furnace 10.

Table 7 shows the lower flammable limit concentrations of various gaseous fuels for use in the present invention and the upper injection limit concentrations (75%, 60%, and 25% of the lower flammable limit concentrations) of those gaseous fuels.

For example, propane gas has a lower flammable limit concentration of 2.2% by volume. Accordingly, the upper limit gas concentration at a dilution of 75% is 1.7% by volume, the upper limit gas concentration at a dilution of 60% is 1.3% by volume, and the gas concentration at a dilution of 25% is 0.6% by volume. Thus, the preferred ranges are as follows, where the lower limit of the diluted gas concentration, that is, the lower limit concentration of propane gas at which the effect of supplying the gaseous fuel appears, is 0.05% by volume:

Preferred range (1): 2.2% to 0.05% by volume

Preferred range (2): 1.7% to 0.05% by volume

Preferred range (3): 1.3% to 0.05% by volume

Preferred range (4): 0.6% to 0.05% by volume

In addition, C-gas has a lower flammable limit concentration of 5.0% by volume. Accordingly, the upper limit gas concentration at a dilution of 75% is 3.8% by volume, the upper limit gas concentration at a dilution of 60% is 3.0% by volume, and the gas concentration at a dilution of 25% is 1.3% by volume. Thus, the preferred ranges are as follows, where the lower limit concentration of C-gas at which the effect of supplying the gaseous fuel appears is 0.24% by volume:

Preferred range (1): 5.0% to 0.24% by volume

Preferred range (2): 3.8% to 0.24% by volume

Preferred range (3): 3.0% to 0.24% by volume

Preferred range (4): 1.3% to 0.24% by volume

In addition, LNG gas has a lower flammable limit concentration of 4.8% by volume. Accordingly, the upper limit gas concentration at a dilution of 75% is 3.6% by volume, the upper limit gas concentration at a dilution of 60% is 2.9% by volume, and the gas concentration at a dilution of 25% is 1.2% by volume. Thus, the preferred ranges are as follows, where the lower limit concentration of LNG gas at which the effect of supplying the gaseous fuel appears is 0.1% by volume:

Preferred range (1): 4.8% to 0.1% by volume

Preferred range (2): 3.6% to 0.1% by volume

Preferred range (3): 2.9% to 0.1% by volume

Preferred range (4): 1.2% to 0.1% by volume

In addition, blast furnace gas has a lower flammable limit concentration of 40.0% by volume. Accordingly, the upper limit gas concentration at a dilution of 75% is 30.0% by volume, the upper limit gas concentration at a dilution of 60% is 24.0% by volume, and the gas concentration at a dilution of 25% is 10.0% by volume. Thus, the preferred ranges are as follows, where the lower limit concentration of blast furnace gas at which the effect of supplying the gaseous fuel appears is 0.24% by volume:

Preferred range (1): 40.0% to 1.25% by volume

Preferred range (2): 30.0% to 1.25% by volume

Preferred range (3): 24.0% to 1.25% by volume

Preferred range (4): 10.0% to 1.25% by volume

Next, Table 8 shows the amounts and calorific values of hydrogen, CO, methane, ethane, and propane contained in C-gas, LNG, and B-gas as combustible components.

Table 7

Type of gas	Lower flammable limit concentration, % to air (Lower explosion limit)	Upper injection limit concentration, % to air (75%)	Upper injection limit concentration, % to air (60%)	Upper injection limit concentration, % to air (25%)	Ignition temperature In air (°C)
Propane	2.2	1.7	1.3	0.4	528 to 588
Hydrogen	4.0	3.0	2.4	0.8	580 to 590
Methane	5.0	3.8	3.0	0.9	650 to 750
CO gas	12.5	9.4	7.5	2.3	658 to 674
Coke oven gas	5.0	3.8	3.0	0.9	About 630
LNG	4.8	3.6	2.9	0.9	About 680
Blast furnace gas	40.0	30.0	24.0	7.5	About 680

Table 8

Type of gas	Hydrogen (vol%)	Nitrogen (vol%)	CO (vol%)	CO_2 (vol%)	Methane (vol%)	Ethane (vol%)	Propane (vol%)	Calorific value (Mcal/m^3)
C-gas	59	-	7	-	34	-	-	4.8
LNG	-	-	-	-	89	5	6	9.5
B-gas	4	61	24	21	-	-	-	0.8

An experiment that paved the way for the development of the method for producing sintered ore according to the present invention will now be described.

This experiment is a sinter pot test conducted using a vertical cylindrical test pot (150 mm in diameter by 400 mm in height) with a transparent quartz window, using a mixture of blast furnace gas and coke oven gas (M-gas) as the gaseous fuel used, and using the same sintering raw material as that used in the sinter plants of the applicant company, that is, the sintering raw material shown in Table 9, at a constant downdraft pressure of 11.8 kPa. Here, the concentration of the combustible component of the M-gas was varied in the range of 0.5% to 15% by volume by dilution with air. The M-gas used in this experiment had a lower flammable limit concentration of 12% by volume.

Table 9

Mix species	Proportion (mass%)
Robe River	9.6
Yandi	23.8
Carajas	42.6
Limestone	16.6
Silica	2.7
Coke fines	4.7

Fig. 28 shows combustion and melting zones observed on video through the transparent quartz window of the test pot, particularly showing the conditions of the combustion zones descending as the combustion fronts propagated. As shown in Fig. 28, when a gaseous fuel containing 15% by volume of M-gas, which exceeds the lower flammable limit concentration (12% by volume), was injected into a mix deposit bed in the test pot, the gaseous fuel started burning promptly at the surface of the sintering bed and did not reach the lower layer of the sintering bed, thus providing no injection effect. In contrast, when a gaseous fuel diluted with air to a concentration of 3% by volume, which does not exceed 75% of the lower flammable limit concentration (12% by volume) of the gaseous fuel, was used according to the present invention, it reached and burned in the deep region of the sintering bed, that is, the region corresponding to the combustion and melting zone, without burning at the surface of the mix deposit bed. As a result, the combustion zone (also referred to as the combustion and melting zone) formed using air alone for sintering had a thickness of 70 mm, whereas the combustion zone formed using the diluted M-gas had a thickness of 150 mm, that is, not less than two times higher. This increase in the thickness of the combustion zone means that the high-temperature-zone holding time can also be extended.

In this experiment using the test pot, additionally, the speed at which the combustion zone descended (the reciprocal thereof is the sintering time), which is equivalent to the speed at which a combustion front propagates as a pallet of an actual sintering machine moves, was increased by supplying the diluted gaseous fuel, and the thickness of the combustion zone in the vertical direction could also be increased, as in the case where the amount of coke is increased or high-temperature air is injected. Thus, it was demonstrated that the injection of a properly diluted gaseous fuel into a sintering bed of sintering raw material provides a greater effect of broadening the combustion zone than the use of a solid fuel, a liquid fuel, or an undiluted flammable gas, as in the conventional art, and also allows the combustion front to propagate substantially at the same speed as in air sintering without decreasing the speed at which the combustion front propagates, unlike the case where the amount of coke is increased.

Figs. 29(a) to 29(d) summarize the results of the above sinter pot test. The injection of the properly diluted M-gas into the mix sintering bed according to the present invention slightly improved the yield (Fig. 29(a)) and increased the sinter productivity (Fig. 29(b)) despite little change in sintering time. Furthermore, the shutter index (SI), serving as a control measure of cold strength, which greatly affects the operational performance of a blast furnace, was improved by not less than 10% (Fig. 29(c)), and the reduction-degradation index (RDI) was improved by 8% (Fig. 29(d)).

In the present invention, a diluted flammable gas is used as the gaseous fuel introduced into the sintering bed. The degree of dilution will now be described. Table 10 shows the lower and upper flammable limit concentrations of blast furnace gas, coke oven gas, a mixture thereof (M-gas), propane, methane, and natural gas. For example, if a gas having such a flammable limit concentration flows toward a ventilator without burning in the sintering bed, it can explode or burn, for example, in an electrostatic precipitator. Hence, the present inventors conducted, by trial and error, numerous experiments using gaseous fuels diluted to concentrations that pose no such risk, that is, concentrations at or below the lower flammable limit, for introduction into the sintering bed, and to ensure higher safety, using diluted gaseous fuels in concentrations of 75% or less of the lower flammable limit concentration. As a result, it was confirmed that no problem arose.

For example, as shown in Table 10, the lower flammable limit of the concentration range where blast furnace gas burns in air at normal temperature is 40% by volume. In other words, it does not burn in a concentration below 40% by volume. The upper flammable limit, on the other hand, is 71% by volume. This means that a blast furnace gas in a concentration above 71% by volume does not burn because of the excessive concentration. The sources of these values will now be described on the basis of the drawings.

Table 10

(vol%)

Type of gas	Lower flammable limit	Upper flammable limit
Blast furnace gas	40.0	71
Coke oven gas	5.0	22
Mixed gas (M-gas)	12.0	42
Propane	2.2	9.35
Methane	4.9	15.0
Natural gas	4.8	13.5

Fig. 30 shows an example of the method for determining the flammable limits of blast furnace gas. The proportions of the combustible components (flammable gases) and others (inert gases) contained in blast furnace gas in the graph are as follows, where they are discussed on the basis of the combination of H_2 and CO_2 and the combination of CO and N_2:

(1) The (inert gas)/(flammable gas) ratio of the combination "H_2 and CO_2" is 20.0/3.5 = 5.7.

The intersections (flammable limits) of the axis of 5.7 on the horizontal axis, which indicates the (inert gas)/(flammable gas) ratio, and the H_2 + CO_2 curve in the combustion limit graph are determined. The lower and upper limits are 32% by volume and 64% by volume, respectively. That is, the lower and upper flammable limits of H_2 and CO_2 are 32% by volume and 64% by volume, respectively.

(2) On the other hand, the (inert gas)/(flammable gas) ratio for the remaining combustible component, namely, the combination "CO and N_2," is 53.5/23.0 = 2.3. Similarly, the lower and upper limits are determined to be 44% by volume and 74% by volume, respectively, from the intersections of the axis of 2.3 on the horizontal axis and the CO + N_2 curve in the graph. Hence, the lower and upper flammable limits in this case are 44% by volume and 74% by volume, respectively.

(3) Furthermore, the lower flammable limit of blast

furnace gas, which contains both combustible components, can be determined from the equation to the left in the bottom of Fig. 30. In addition, the upper flammable limit can also be determined by substituting the upper limits of Items (1) and (2) into the equation. In this way, the lower and upper flammable limits of blast furnace gas can be determined.

Another reason for focusing on the lower flammable limit of the gaseous fuel in the present invention is that the flammable limit has temperature dependence. According to "Nenryo Binran (Handbook of Fuels)" (edited by the Fuel Society of Japan), as the effect of temperature, heat dissipation speed becomes lower at a higher temperature, so that the intersection of heat generation and dissipation speed curves becomes deeper, thus broadening the explosion range (combustion range) laterally. That is, whereas the flammable limit can be determined as described above, the flammable limit has temperature dependence, and "Nenryo Binran (Handbook of Fuels)" (edited by the Fuel Society of Japan) shows the example in Table 11 as the effect of temperature on the combustion range of methane gas. This can be used to draw a graph of the temperature dependence of the lower flammable limit concentration, as shown in Fig. 31, where the black circles indicate the example of methane gas in Table 11.

Table 11

Temperature (°C)	Flammable range (vol%)
17	6.0 to 13.0
100	5.95 to 13.7
200	5.50 to 14.5
300	5.10 to 15.5
400	4.8 to 16.6

In addition, Fig. 32 shows the relationship between temperature and the combustible component (combustion gas) concentration of the gaseous fuel in air at normal temperature. Whereas the flammable limit can be determined as described above, the flammable limit has temperature dependence. To illustrate the temperature dependence tendency, the lower flammable limit (corresponding to the combustion gas concentration in the graph), which is about 40% by volume at normal temperature, changes to 26% to 27% by volume in the range around 200°C and to several percents in the range around 1,000°C, and the gaseous fuel burns even in a concentration below 1% by volume in the range around 1,200°C.

From this, it was found that a higher safety is ensured if the concentration (combustible component content) of the gaseous fuel supplied to the sintering bed is lower than the lower flammable limit at normal temperature and that the position where the gaseous fuel is combusted in the sintering bed in the thickness direction thereof can be controlled with increased flexibility only if the concentration of the diluted gas is adjusted to an appropriate range.

It was also found that the combustion of the gaseous fuel has such temperature dependence and, for example, the combustion range becomes broader at a higher ambient temperature, and that a gaseous fuel in a concentration as shown in the preferred examples of the present invention burns well in the temperature field around the combustion and melting zone of the sintering machine but does not burn in a temperature field around 200°C, such as in an electrostatic precipitator disposed downstream of the sintering machine.

In the production of sintered ore, the diluted gaseous fuel supplied to the sintering bed of the sintering raw material is sucked through the wind boxes disposed below the pallet and is combusted in the high-temperature combustion and melting zone formed by combustion of the solid fuel (coke fines) in the sintering bed. Accordingly, the amount of coke fines in the sintering raw material can be adjusted (reduced) if the diluted gaseous fuel is supplied while controlling, for example, the concentration and amount of diluted gaseous fuel supplied with the calorific value supplied to the sintering bed remaining constant. In addition, the concentration adjustment of the diluted gaseous fuel means to control the combustion of the gaseous fuel so that the combustion of the gaseous fuel occurs at the intended position (concentration region) in the sintering bed.

In this meaning, the combustion and melting zone in the sintering bed in the conventional art is a zone where only the solid fuel (coke fines) is combusted, whereas the combustion and melting zone in the sintering bed in the present invention is a zone where the coke fines are combusted together with the gaseous fuel. In the present invention, therefore, if the supply conditions, including the concentration and amount of diluted gaseous fuel supplied, are appropriately changed in relation to coke fines taking into account the presence of coke fines as part of the fuel, the ultimate maximum temperature and/or the high-temperature-zone holding time can be appropriately controlled for improved strength of sinter cake.

Another reason for using the diluted gaseous fuel in the method of the present invention is to control the strength and yield of sinter cake by controlling the form of the combustion and melting zone described above. The diluted gaseous fuel plays an effective role in controlling how long the sinter cake is maintained in the high-temperature region (combustion and melting region) and what temperature is reached. In other words, the use of the diluted gaseous fuel means to control the high-temperature-zone holding time in the sintering raw material so that it becomes longer and the ultimate maximum temperature so that it becomes moderately high. Such control also means to use a gaseous fuel diluted and adjusted depending on the amount of solid fuel (amount of coke fines) in the sintering raw material so that the amount of combustion-supporting gas (air or oxygen) in the combustion atmosphere is not excessive or insufficient. In this regard, in the conventional art, the amount of combustion-supporting gas (oxygen) matching the amount of solid fuel and flammable gas is not supplied because the flammable gas is injected irrespective of the amount of solid fuel in the sintering raw material and without adjusting the concentration of the flammable gas, and this results in insufficient combustion or, conversely, partial excessive combustion, thus causing variations in strength. That is, the present invention avoids that problem by the dilution and concentration adjustment of the gaseous fuel.

Next, the effect of the diluted gaseous fuel depending on the type of gaseous fuel will be shown. Fig. 33 shows the experimental results of a comparison between a sintering method of the present invention using several types of gaseous fuels diluted to a concentration at or below the lower flammable limit concentration and a conventional sintering method without injection of a gaseous fuel. In the conventional sintering method without injection of a gaseous fuel, 5% by mass of coke fines were added. On the other hand, in the sintering method of the present invention with injection of a diluted gaseous fuel, the diluted gaseous fuel was injected in an amount equivalent to 0.8% by mass of coke fines, and accordingly 4.2% by mass of coke fines were added so that the total calorific value remained constant. As shown in the diagram, the shutter index, the product yield, and the productivity were improved in any of the examples using a diluted gaseous fuel. The reason why the shutter index, the product yield, etc. were improved in the examples using a diluted gaseous fuel is that the combustion and melting zone was broadened, as shown in the combustion conditions, and accordingly the high-temperature-zone holding time was extended.

Fig. 34 shows graphs showing the effect of the injection gas concentration in the case where propane gas was used as the gaseous fuel, showing the relationships between the concentration of the diluted gaseous fuel and (a) the shutter index, (b) the yield, (c) the sintering time, and (d) the productivity. As shown in the graphs, if propane gas is used as the diluted gaseous fuel, the effect of improving the shutter index appears at 0.05% by volume, and the effect of improving the yield appears similarly.

For propane gas, a noticeable effect appears at 0.1% by volume or more, preferably 0.2% by volume. If this result is applied to the case where C-gas is used as the injection gas, the effect of C-gas appears at 0.24% by volume, preferably 0.5% by volume or more, and a noticeable improvement effect appears at 1.0% by volume or more. Accordingly, the amount of propane gas added is at least 0.05% by volume or more, preferably 0.1% by volume or more, and more preferably 0.2% by volume or more. The amount of C-gas added, on the other hand, is at least 0.24% by volume or more, preferably 0.5% by volume or more, and more preferably 1.0% by volume or more, and the upper limit is 75% of the lower flammable limit. For propane gas, the effect is almost saturated at 0.4% by volume, which is equivalent to 25% of the lower flammable limit.

Next, the cold strength and reduction-degradation index (RDI) of the sintered ore produced by supplying the gaseous fuel taking into account the amount of carbonaceous material in the sintering raw material according to the method of the present invention will be described. According to "Kobutsu Kogaku (Mineral Engineering)" (edited by Hideki Imai, Sukune Takenouchi, and Yoshinori Fujiki, 1976, 175, Asakura Publishing Co., Ltd.), the sintering reaction is summarized as in the schematic diagram in Fig. 35. In addition, Table 12 shows the values of tensile strength (cold strength) and reducibility of various ores formed during the sintering process. As shown in Fig. 35, a melt starts to be formed at 1,200°C during the sintering process, and calcium ferrite is formed, which has the highest strength of the constituent ores of sintered ore and also has relatively high reducibility. As the temperature rises and exceeds about 1,380°C, calcium ferrite is decomposed into amorphous silicate salt (calcium silicate), which has the lowest cold strength and reducibility, and secondary hematite, which is susceptible to reduction degradation. To improve the cold strength and RDI of sintered ore, therefore, it is important whether calcium ferrite can be stably maintained without decomposition.

Table 12

Type of ore	Tensile strength (MPa)	Reducibility (%)
Hematite	49	50
Magnetite	58	22
Calcium ferrite	102	35
Calcium silicate	19	3

The above publication "Kobutsu Kogaku" also describes the precipitation behavior of secondary hematite, which is the origin of reduction degradation of sintered ore, with reference to Fig. 36. According to that description, the results of an ore synthesis test show that, because skeleton-crystal secondary hematite, which is the origin of reduction degradation, precipitates after calcium ferrite is heated to the Mag.ss + Liq. range in the phase diagram and is then cooled, the reduction degradation can be inhibited by producing a sintered ore through path (2), rather than through path (1). To produce a sintered ore having both low RDI and high strength, therefore, it is important how to achieve a heat pattern in which the temperature in the sintering bed is maintained within the range of 1,200°C (solidus temperature of calcium ferrite) to about 1,380°C (transition temperature) over an extended period of time. Accordingly, it is important to adjust the amount of carbonaceous material added depending on the amount of gaseous fuel supplied to control the ultimate maximum temperature in the sintering bed to the range of more than 1,200°C to less than 1,380°C, preferably 1,205°C to 1,350°C.

Next, to determine the relationship between the thickness (width) of the combustion zone in the vertical direction and the diluted fuel gas, the prevent inventors conducted an experiment in which a propane gas diluted with exhaust gas from a sintering machine cooler was injected into a sintering bed of sintering raw material in a vertical cylindrical test pot with a transparent quartz window from above the pot. The sintering raw material used in this experiment was a common sintering raw material used by the applicant company, and the suction pressure was maintained at 1,200 mmAq. In this experiment, propane gases diluted to concentrations of 0.5% and 2.5% by volume were injected. In terms of the calorific value supplied, 0.5% by volume of propane injected is substantially equivalent to 1% by mass of coke fines.

Fig. 37 shows photographs showing the forms of combustion zones observed when propane gas was injected in this experiment. As shown in the diagram, the propane gas diluted to 2.5% by volume, which is close to the lower flammable limit concentration (theoretical value, with respect to air), burned above the mix sintering bed immediately after the injection and did not enter the sintering bed, thus providing no gaseous fuel supply effect. On the other hand, the propane gas diluted to a concentration of 0.5% by volume with respect to air entered the sintering bed without burning above the sintering bed and burned at high speed in the sintering bed. As a result, whereas the width (thickness) of the combustion zone in the vertical direction for sintering in air was about 70 mm, the width of the combustion zone for injection of the diluted propane gas was 150 mm, that is, not less than two times higher. This means that the high-temperature-zone holding time was extended.

Thus, it was found that the effect of increasing the thickness of the combustion zone appears even at a concentration of 0.5% by volume, which is one fifth of the lower flammable limit concentration of propane. Conversely, it was also found that the control of combustion in the sintering bed by the gaseous fuel injection technique according to the present invention is difficult unless a diluted gaseous fuel is used.

In this experiment, additionally, the speed at which the combustion zone descended (the reciprocal thereof is the high-temperature-zone holding time) was examined. As a result, whereas simply increasing the amount of coke or injecting high-temperature air greatly decreases the speed at which the combustion zone descends and therefore decreases the productivity, the speed at which the combustion zone descended differed negligibly between the sintering using the diluted gaseous fuel and the air sintering. This is because the combustion speed can be increased as compared to the case where the amount of solid fuel is increased.

Next, to examine the effect of the position where the diluted gaseous fuel is supplied in the sintering bed, the present inventors conducted a sinter pot experiment using a coke oven gas (C-gas) diluted to 2% as the gaseous fuel, where the diluted gaseous fuel was injected between positions 100 and 200 mm from the surface of the sintering bed, between positions 200 and 300 mm from the surface of the sintering bed, and between positions 300 and 400 mm from the surface of the sintering bed. The results are shown in Fig. 38.

Here, the injection between positions 100 and 200 mm from the surface of the sintering bed, shown along the horizontal axis in Fig. 38, refers to an example in which the diluted gaseous fuel was injected and combusted during the period of time after the combustion and melting zone, looking bright (white) in the diagram, reaching a position 100 mm from the surface of the sintering bed, when the supply of the diluted gaseous fuel from above the test pot was started, until the combustion and melting zone reached a position 200 mm from the surface of the sintering bed. The observation results of the propagation process of the combustion and melting zone (the combustion and melting zone looks bright (white) in the diagram) in this case are shown along the vertical axis. Similarly, the injection between positions 200 and 300 mm from the surface of the sintering bed refers to an example in which the diluted gaseous fuel was supplied and combusted during the period of time after the combustion and melting zone reaching a position 200 mm from the surface of the sintering bed until it reached a position 300 mm from the surface of the sintering bed, and the injection between positions 300 and 400 mm from the surface of the sintering bed refers to an example in which the diluted gaseous fuel was supplied and combusted during the period of time after the combustion and melting zone reaching a position 300 mm from the surface of the sintering bed until it reached a position 400 mm from the surface of the sintering bed. For comparison, a conventional method without injection of a diluted gaseous fuel was also examined for the propagation condition of the combustion and melting zone. Because the combustion air supplied to the test pot flew from top to bottom, as in a normal sinter operation, the gaseous fuel was added and supplied to the combustion air so as to attain the intended concentration.

As shown in Fig. 38, the thickness of the combustion and melting zone in the case where the diluted gaseous fuel was supplied while the combustion and melting zone was located in the region between positions 100 and 200 mm from the surface of the sintering bed was only slightly larger than in the conventional method. On the other hand, the thickness of the combustion and melting zone in the case where the diluted gaseous fuel was supplied while the combustion and melting zone was located in the region between positions 200 and 300 mm from the surface of the sintering bed was noticeably larger than in the conventional method. A noticeable difference also occurred between the case where the diluted gaseous fuel was supplied while the combustion and melting zone was located in the region between positions 300 and 400 mm from the surface of the sintering bed and the conventional method.

Accordingly, the diluted gaseous fuel is preferably injected into a portion where the combustion and melting zone is located in the region below a position 200 mm from the surface of the sintering bed. The gaseous fuel does not have to be supplied to the region above a position 200 mm from the surface of the sintering bed because if the gaseous fuel is supplied to the region below a position 200 mm from the surface of the sintering bed, the shutter index of sintered ore in that region can be significantly improved, so that the yield of sintered ore products can be improved as a whole. Thus, the cost of the gaseous fuel can also be reduced.

Fig. 39 schematically shows the combustion conditions of the upper layer above a position 200 mm from the surface of the charged layer and the middle and lower layers below a position 200 mm from the surface of the sintering bed. Arrows A shown in the diagram indicate the direction in which sintering proceeds (fuel direction), and Fig. 39(a) shows the positions where coke fines and the gaseous fuel burned in the upper layer (less than 200 mm). In this case, the temperature pattern shown to the right of the diagram is obtained because the combustion zone formed by the coke fine fuel is originally narrow in the upper portion of the sintering bed and is close to the point of combustion of the gaseous fuel combusted in the combustion zone. In this temperature distribution, the combustion zone of coke fines (solid fuel) is shown as a hatched portion, and the temperature range where the gaseous fuel burns thereabove is shown as an unhatched portion. As shown in the diagram, the high-temperature-zone holding times (equivalent to about 1,200°C), denoted by T_1 and T_2 in the diagram, are short because the coke and the gaseous fuel burn concurrently (both burn in proximity to each other) in the upper portion of the sintering bed. That is, the coke combustion zone, shown as the hatched portion, is only slightly broadened. This agrees with the fact that the effect of injecting the gaseous fuel is small if the original high-temperature-zone holding time is short, and accordingly the gaseous fuel is preferably supplied to the sintering bed after the thickness of the combustion and melting zone reaches 15 mm or more.

Fig. 39(b), on the other hand, shows the case where the gaseous fuel was supplied to the middle and lower layers. The combustion zone is broadened with increasing temperature in the sintering bed as the combustion zone propagates from top to bottom so that the gaseous fuel burns at a farther position than in the case in Fig. 39(a). As a result, the temperature distribution shown in the right of Fig. 39(b) is obtained. That is, the combined temperature distribution curve shows a broad temperature distribution because the point of combustion of the gaseous fuel is remote from the point of combustion of the solid fuel (coke), shown by hatching. Accordingly, the high-temperature-zone holding time based on the combustion of the solid fuel and the gaseous fuel, denoted by T_3 and T_4, is extended so that the resultant sintered ore has improved shutter index.

In the case in Fig. 39(b), the ignition temperature of the gaseous fuel for controlling (extending) the high-temperature-zone holding time is preferably 400°C to 800°C, more preferably 500°C to 700°C. The reason is that if the ignition temperature falls below 400°C, it is only possible to broaden the low-temperature range distribution, rather than the high-temperature range, and if the ignition temperature exceeds 800°C, the effect of extending the high-temperature-zone holding time is small because the high-temperature-zone holding time is excessively close to that due to the combustion of the solid fuel and only results in a rise in ultimate maximum temperature.

Fig. 40 shows the measurement results of the temperature profile of a test pot during sintering, where the example shown to the left is a conventional sintering method using coke fines alone, and the example shown to the right is a method using a diluted town gas (LNG). According to the results in Fig. 40, for the conventional sintering method using coke fines alone, shown to the left, the region where the temperature was 1,200°C or more (pale yellow region) was small, while the region where the maximum temperature exceeded 1,400°C (white region) was large. On the other hand, for the method using a diluted town gas, shown to the right, the coke fines burned at the lower end of the combustion zone, LNG burned in the portion thereabove, and a region where the temperature was slightly lower was present between the position where the coke fines burned (the lower end of the combustion zone) and the position where the LNG burned (the portion above the melting zone). If LNG is combusted so that the region where the temperature is slightly lower reaches a temperature of 1,200°C or more, the region where the temperature is 1,200°C or more is extensively distributed while the maximum temperature is lowered due to the reduced amount of coke fines used. As a result, the high-temperature-zone holding time is extended.

Fig. 41 summarizes the temperature histories during the sintering based on the above thermoviewer results. By injecting LNG, the area of the region where the temperature was 1,200°C or more could be increased to about twice that in the case where sintering was performed using coke fines alone without the maximum temperature exceeding 1,400°C, preferably 1,380°C. In addition, two peaks were observed in the temperature pattern: the first peak (peak closer to the upper layer of the mix bed) is due to the combustion of LNG injected into the portion above the coke combustion zone, and the second peak (peak closer to the lower layer of the mix bed) is due to the combustion of coke. It is assumed that the temperature pattern resulted from the combination of the temperature variations due to their combustion. That is, the ultimate maximum temperature due to the combustion of coke (carbonaceous material) was controlled by combusting the coke and the injected town gas at different positions in combination (second peak), and the region therebetween was maintained at 1,200°C or more by the subsequent combustion of LNG (first peak), so that the high-temperature-retained region where the temperature was 1,200°C or more, forming the combustion and melting zone effective in forming sintered ore, was significantly broadened. As a result, the high-temperature-zone holding time in the combustion and melting zone was continuously extended, thus significantly improving the strength of sintered ore products.

Next, an example of a method for controlling the ultimate maximum temperature in the sintering bed (in-bed temperature) by supplying a diluted gaseous fuel will be described. Fig. 42 schematically shows temperature distributions in sintering beds during sintering, illustrating a sintering method according to the present invention in which a diluted C-gas is injected and the amount of coke is correspondingly reduced, where a temperature distribution obtained by adding 5% by mass of solid fuel (coke fines), which corresponds to a conventional sintering method, serves as a reference. Here, curve a indicates the relationship between in-bed temperature and time for the conventional sintering method in which sintering is performed by adding 5% by mass of coke. In general, the high-temperature-zone holding time is extended by increasing the amount of coke fines added. For example, as indicated by the curve for the case where 10% by mass of coke fines are added, namely, broken line b, the high-temperature-zone holding time is increased from (0-A) to (0'-B) if the amount of coke is increased. At the same time, however, the ultimate maximum temperature rises from about 1,300°C to about 1,400°C, and therefore a sintered ore having low RDI and high strength cannot be achieved.

In this regard, the sinter operation process according to the method of the present invention (curve c), in which a diluted C-gas is injected while reducing the amount of coke fines to 4.2% by mass, can limit the ultimate maximum temperature to 1,380°C while increasing the high-temperature-zone holding time to (0-C), thus sufficiently achieving the initial object, that is, the production of a sintered ore having low RDI and high strength that is not achieved by a conventional method.

In summary, conventional sintering methods are operating methods focusing on either the high-temperature-zone holding time or the maximum temperature control. The method of the present invention, in contrast, is an operating method for adjusting the high-temperature-zone holding time by injecting a diluted gaseous fuel while adjusting the ultimate maximum temperature (to 1,205°C to 1,380°C) by adjusting the amount of coke fines used (for example, to 4.2% by mass). Curve d in Fig. 40, indicating an example in which the amount of solid fuel used is simply reduced to 4.2% by mass, has a low ultimate maximum temperature and a short high-temperature-zone holding time.

Fig. 43 shows the combustion conditions of an example of a conventional sintering method using 5% by mass of coke fines and an example according to the present invention using 4.2% by mass of coke fines in combination with injection of a C-gas diluted to a concentration of 2.0% by volume. As shown in the thermoviewer images in the diagram, a combustion condition exceeding 1,400°C occurred in the conventional method. In contrast, in the example of the present invention, in which a C-gas in a concentration of 2% by volume was injected while reducing the amount of coke fines used to 4.2% by mass, it was found that the high-temperature-zone holding time could be extended while limiting the ultimate maximum temperature to 1,380°C or less without forming a 1,400°C region.

Fig. 44 shows changes over time in (a) the temperature in the sintering bed, (b) the temperature of exhaust gas, (c) the volume of air passed, and (d) the composition of exhaust gas due to injection of a diluted propane gas with the calorific value supplied remaining constant. The temperature in the sintering bed was measured in the above test.pot using a thermocouple inserted to a position 400 mm below the surface of the sintering bed (sintering bed thickness: 600 mm) at two positions in the circumferential direction of the test pot, namely, the center and a position 5 mm from the wall. According to these graphs, it was demonstrated that the injection of the diluted propane gas allowed the sintering raw material to be heated to not less than 1,205°C and the melting time (high-temperature-zone holding time) was increased not less than two times without raising the ultimate maximum temperature. In addition, the oxygen concentration of the exhaust gas was decreased by injecting the propane gas as the diluted gaseous fuel, suggesting that oxygen was efficiently used for the combustion reaction.

In addition, Fig. 45 shows changes over time in (a) the temperature in the sintering bed and (b) the temperature of exhaust gas in the case where a diluted propane gas was injected (0.5% by volume) in contrast with changes over time in (a') the temperature in the sintering bed and (b') the temperature of exhaust gas in the case where the amount of coke was increased (10% by mass). According to these graphs, in the case where the amount of coke fines used was doubled, the high-temperature-zone holding time, that is, the time during which the temperature was 1,200°C or more, was substantially equivalent to that in the case where the propane gas diluted to a concentration of 0.5% by volume was injected, although the ultimate maximum temperature exceeded 1,380°C. In addition, the increase in the amount of coke fines significantly increased the CO_2 concentration of the exhaust gas, namely, from 20% to 25% by volume, and also increased the CO concentration, demonstrating that the contribution of coke fines to combustion was decreased.

Next, a sintering experiment was carried out under the conditions shown in Table 13 to examine the effect on the operating condition and the quality of sintered ore. In Test No. 1, serving as the current base conditions, 5% by mass of coke was added to a sintering raw material. In Test No. 2, the amount of coke fines was decreased by 1% by mass, namely, to 4% by mass, and 0.5% by volume of propane gas was injected instead so that the calorific value supplied remained constant. In Test No. 3, 10% by mass of coke fines were added. In Test No. 4, high-temperature gas at 450°C was injected for the purpose of verifying the difference from a heat-retaining furnace (Japanese Unexamined Patent Application Publication No. 60-155626).

Table 13

Test No.	No. 1	No. 2	No. 3	No. 4
Coke fine proportion (to mix, mass%)	5	4	10	5
Propane concentration (to air, vol%)	0	0.5	0	0
Heat-retaining furnace (injection of hot air at 450°C)	OFF	OFF	OFF	ON

Fig. 46 summarizes the results of various property tests in these tests. As is evident from these graphs, the injection of the diluted propane gas slightly extended the sintering time but improved the yield, the shutter index (SI), and the productivity and also significantly improved the reduction-degradation index (RDI) and the reducibility index (RI). Thus, it was demonstrated that proper injection of a diluted gaseous fuel improves the productivity, the yield, and the quality of sintered ore.

In contrast, in the case where the amount of coke fines was simply increased to 10% by mass, the sintering time was extended, and the shutter index and the yield were both significantly decreased because the excessive rise in ultimate maximum temperature resulted in formation of a large amount of low-strength amorphous silicate salt. In addition, in the case where high-temperature gas at 450°C was injected, the effect of improving the shutter index and the yield was small, agreeing with the results of existing commercial equipment.

As described above, if a diluted gaseous fuel is used, the gas burns in the sintering bed to broaden the combustion zone in the bed, and a broad combustion zone is formed by the synergy between combustion heat from the coke in the sintering raw material and combustion heat from the diluted propane gas. As a result, the high-temperature-zone holding time can be extended without excessively raising the ultimate maximum temperature.

Next, the present inventors examined the effect of the injection of a diluted gaseous fuel on the reducibility, cold strength, etc. of sintered ore products in contrast with conventional methods (5% by mass of coke, 10% by mass of coke, and hot air injection). The measured items were the ore phase composition (which affects the cold strength and the reducibility), the apparent specific gravity (which affects the cold strength), and the distribution of pores with diameters of 0.5 mm or less (which affects the reducibility) of sintered ore products.

Fig. 47 shows the examination results of the ore phase compositions of the sintered ore products determined by powder X-ray diffractometry. This graph shows that calcium ferrite formed stably when the solid fuel and the diluted propane gas were used in combination with the calorific value supplied remaining constant (4% by mass of coke and 0.5% by volume of propane), which contributes to improved reducibility and increased cold strength.

Fig. 48 shows the measurement results of variations in the apparent specific gravity of the sintered ore products with and without injection of propane gas, and Fig. 47 shows the measurement results of variations in the distribution of pores with diameters of 0.5 mm or less measured using a mercury intrusion porosimeter with and without injection of propane gas. Fig. 46 shows that the injection of the propane gas increased the apparent specific gravity. This is because the injection of the propane gas caused the granulated particles to be externally heated to facilitate melt flow, thus decreasing the porosity for pores with diameters of 0.5 mm or more. This result contributes to improved cold strength. In addition, Fig. 49 shows that the injection of the diluted propane gas with the calorific value supplied remaining constant increased the distribution of pores with diameters of 0.5 mm or less. This is because the heat source in the sintering raw material particles was reduced so that more ore-derived fine pores with diameters of 500 μm or less, which affect the reducibility, remained. This allows production of a sintered ore with high reducibility.

Fig. 50 schematically shows sintering behaviors in (a) the case where coke is used alone and (b) the case where coke is used in combination with a diluted gaseous fuel. As shown in the diagram, whereas the quasi-particles are internally heated by combustion of coke fines in the conventional sintering method using coke alone, the quasi-particles are also externally heated by combustion of the gaseous fuel in the method using coke and the gaseous fuel in combination according to the present invention. This allows more fine pores in the ore to remain so that the reducibility index (RI) can be made relatively high despite low RDI.

Fig. 51 schematically shows variations in the pore distribution of sintered ore in the case where a diluted gaseous fuel is injected. As shown in this graph, it is effective in improving the productivity of sintered ore to reduce the number of pores having diameters of 0.5 to 5 mm, which affect the yield and the cold strength, by facilitating integration thereof, and to increase the proportion of pores having diameters of 5 mm or more, which affect the permeability. In addition, to improve the reducibility of sintered ore, it is preferable to form a porous structure in which more fine pores having diameters of 0.5 mm or less, mainly present in iron ore, remain. In this regard, according to the present invention, a sintered ore having a porous structure closer to the ideal porous structure can be achieved by injecting a diluted gaseous fuel.

Fig. 52 shows the results of a test for determining a critical coke proportion at which the desired cold strength can be maintained. Here, the critical coke proportion is defined as the amount of coke added in which the shutter index (SI) is equivalent to the maximum value (73%) obtained without using a diluted propane gas. As shown in these graphs, by injecting 0.5% by volume of diluted propane gas, the coke proportion at which the same cold strength as the current cold strength (shutter index of 73%) could be achieved was decreased from 5% by mass to 3% by mass (about 20 kg/t), as shown in Fig. 50(a). In addition, as shown in Figs. 50(b) and 50(c), the coke proportion at which a yield of 74% and a productivity of 1.86 t/hr·m^2 were achieved were decreased from 5% by mass to 3.5% by mass.

As is evident from the above description, the present invention provides the effect of broadening the function of the combustion and melting zone in the sintering bed by supplying a gaseous fuel appropriately diluted depending on the amount of carbonaceous material contained to an appropriate position while the combustion and melting zone propagates from the surface layer to the lower layer of the sintering bed as the pallet moves, thereby improving the quality of sintered ore and the productivity.

EXAMPLE 1

A sinter pot test of a sintering raw material containing 5% by mass of carbonaceous material (coke) using the test pot shown in Fig. 28 was carried out using coke oven gases (C-gases) diluted to 1 to 2.5% by volume as gaseous fuels, where the other conditions were the same as the experimental conditions described above (paragraph 0099). The results are shown in Fig. 51. As shown in the diagram, it was found that if a C-gas diluted according to the method of the present invention is used, increasing the concentration of C-gas significantly increases the width (thickness) of the combustion zone and also improves the yield, the productivity, and the cold strength (SI).

EXAMPLE 2

A sinter pot test of a sintering raw material containing 5% by mass of carbonaceous material (coke) was carried out using propane gases diluted to 0.02 to 0.5% by volume as diluted gaseous fuels, where the other conditions were the same as those of Example 1. The results are shown in Fig. 52. As shown in the diagram, it was found that if a propane gas diluted according to the method of the present invention is used, increasing the concentration of propane gas significantly increases the width (thickness) of the combustion zone and also improves the yield, the productivity, and the cold strength (SI).

EXAMPLE 3

As shown in Table 14, sintering pot tests (Nos. 2 to 7) using the test pot shown in Fig. 28 were carried out by injecting coke oven gases (C-gases) diluted to two levels, namely, 1.0% by volume and 2.0% by volume (with respect to air), with cooler exhaust gas from above the pot into sintering beds of sintering raw materiales whose coke fine contents were at two varying levels, namely, 4.9% by mass and 4.8% by mass (excluded from the total). In addition, as a comparative example, a sintering pot test (No. 1) in which the coke fine content was 5.0% by mass (excluded from the total) and no diluted gas was injected was similarly carried out. In this example, the total thickness of the sintering raw material charged into the test pot was 600 mm, the sintering raw materiales containing coke fines were deposited in the upper layer extending 400 mm from the surface of the sintering bed, and return ore was deposited in the lower layer extending 200 mm therebelow.

In addition, the above diluted C-gases were introduced into the sintering bed when the combustion and melting zone was located between positions 100 and 200 mm from the surface of the sintering bed, between positions 200 and 300 mm from the surface of the sintering bed, and between positions 300 and 400 mm from the surface of the sintering bed at a suction pressure of 1,200 mmAq (pressure difference: 1,000 mmAq). For a DL sintering machine having a length of 80 m, the injection between positions 100 and 200 mm from the surface of the sintering bed is equivalent to an example in which a sinter operation is carried out by injecting a diluted gaseous fuel using a 13.3 m long gaseous fuel supply unit disposed at a position of 80 (m) × (100 to 200)/600 (mm) = 13.3 to 26.6 (m), that is, between positions 13.3 and 26.6 m from the origin of movement of the pallet in the movement direction of the pallet. Similarly, the injection between positions 200 and 300 mm from the surface of the sintering bed is equivalent to an example in which a sinter operation is carried out using a 13.3 m long gaseous fuel supply unit disposed between positions 26.6 and 39.9 m from the origin of movement of the pallet, and the injection between positions 300 and 400 mm from the surface of the sintering bed is equivalent to an example in which a sinter operation is carried out using a 13.3 m long gaseous fuel supply unit disposed between positions 39.9 and 53.2 m from the origin of the movement of the pallet.

Table 14

<Test conditions>

Conditions	Test No.	1	2	3	4	5	6	7
Mix proportion (mass%)	Yandi (-8mm)	33.76	33.76	33.76	33.76	33.76	33.76	33.76
	Carajas (-8mm)	33.76	33.76	33.76	33.76	33.76	33.76	33.76
	Silica (-1mm)	2.24	2.24	2.24	2.24	2.24	2.24	2.24
	Burnt lime	1.52	1.52	1.52	1.52	1.52	1.52	1.52
	Limestone (-3mm)	8.72	8.72	8.72	8.72	8.72	8.72	8.72
	Return ore	20.00	20.00	20.00	20.00	20.00	20.00	20.00
	Coke (-3mm)	(5.0)	(4.9)	(4.9)	(4.9)	(4.8)	(4.8)	(4.8)
Gas injection conditions	Injection gas	None (Base)	C-gas	C-gas	C-gas	C-gas	C-gas	C-gas
	Concentration (vol% to air)	-	1.0	1.0	1.0	2.0	2.0	2.0
	Supply position (surface: 0 mm)	-	100 to 200 mm	200 to 300 mm	300 to 400 mm	100 to 200 mm	200 to 300 mm	300 to 400 mm
Bed thickness (mm)		400	400	400	400	400	400	400
Pressure difference (mmAq)		1000	1000	1000	1000	1000	1000	1000
Remarks								

*The coke proportion is excluded from the total.

Table 15 shows the results of the above sintering pot tests. According to these results, the invention examples in which the gaseous fuel was injected, namely, Nos. 2 to 7, had improved cold strengths (SI strengths) of sintered ore and yields as compared to the comparative example in which no gaseous fuel was injected, namely, No. 1, and particularly, the improvement was significant in Nos. 3, 4, 6, and 7, in which the gaseous fuel was injected into the middle or lower layer of the sintering bed. In addition, it was found that the productivity is highest if the amount of coke is 4.9% by mass and the C-gas concentration is 1% by volume. Furthermore, as for the effect of the position where the diluted gaseous fuel is injected (supplied) on the quality of sintered ore, it was found that it is most effective in terms of both reducibility index (RI) and reduction-degradation index (RDI) to supply the gaseous fuel when the combustion and melting zone is located in the middle layer between positions 200 and 300 mm from the surface of the sintering bed.

Table 15

<Test results>

Results		Test No.	1	2	3	4	5	6	7
Moisture content of mix (%)			6.70	6.93	6.84	7.20	7.04	7.24	7.19
Amount of charge on wet basis (wet·kg)			12.7	12.7	12.7	12.7	12.7	13.0	13.0
Density of charge on wet basis (wet·ton/m^3)			1.80	1.80	1.80	1.80	1.80	1.84	1.84
Amount of charge on dry basis (dry·kg)			11.8	11.8	11.8	11.8	11.8	12.1	12.1
Density of charge on dry basis (dry·ton/m^3)			1.68	1.67	1.67	1.67	1.67	1.71	1.71
Air pressure before ignition (mmH_2O)			981	981	974	979	995	978	963
Exhaust gas temperature (°C)			283	320	323	323	305	320	331
Amount of mix fired (kg)			10.4	10.5	10.3	10.5	10.4	10.6	10.9
Amount of product (kg)			7.5	7.6	7.3	7.3	7.3	7.5	7.7
SI strength (%)			68.9	70.3	73.1	72.9	69.3	74.1	73.8
Product yield (%)			71.2	72.0	72.6	72.7	69.9	73.5	75.5
Sintering time (min.)			15.9	15.9	14.6	14.9	14.8	15.9	16.3
Productivity (t/h/m^2)			1.59	1.61	1.74	1.73	1.67	1.71	1.68
Position (mm)	100 to 200	Ultimate maximum temperature (°C)	1250	1240	1240	1240	1230	1230	1230
		High-temperature-zone holding time (>1200°C) (sec.)	30	33	30	30	35	30	30
	200 to 300	Ultimate maximum temperature (°C)	1290	1280	1280	1280	1270	1270	1270
		High-temperature-zone holding time (>1200°C) (sec.)	45	45	60	45	45	80	45
	300 to 400	Ultimate maximum temperature (°C)	1360	1330	1330	1330	1320	1320	1320
		High-temperature-zone holding time (>1200°C) (sec.)	60	50	60	100	60	70	120
Reducibility index (RI)			67.4	78.1	85.4	76.3	74.4	77.7	76.6
Reduction-degradation index (RDI)			29.3	31.6	30.8	32.2	29.9	30.9	30.0
T.Fe (%)			59.5	59.0	59.7	59.6	59.7	59.7	59.6
FeO (%)			9.8	9.3	10.1	9.5	8.9	9.5	9.5

EXAMPLE 4

The method for producing sintered ore according to the present invention was applied to a DL sintering machine with a daily production of 20,000 tons. The DL sintering machine used had a length of 90 m from an ignition furnace to a discharge section, and a gaseous fuel supply unit was disposed at a position about 30 m behind the ignition furnace of the sintering machine. This gaseous fuel supply unit included nine gaseous fuel supply pipes having a length of 15 m (in the movement direction of the pallet) and arranged in parallel along the movement direction of the pallet at a height of 500 mm above the sintering bed. Each pipe had 149 nozzles, for ejecting a gaseous fuel downward, arranged at intervals of 100 mm (1,341 nozzles in total). As a gaseous fuel, town gas was ejected from the nozzles into air at high speed so as to be supplied to the sintering bed as a diluted gaseous fuel having a town gas concentration of 0.8% by volume. The total thickness of the sintering bed was 600 mm (where a sintering raw material containing 4.2% by mass of coke fines was deposited in the upper layer extending 400 mm from the surface of the sintering bed). The position where the gaseous fuel was supplied is equivalent to the position where the combustion and melting zone is located between positions 200 and 300 mm from the surface of the sintering bed. The diluted gaseous fuel, supplied as described above, was sucked and introduced into the sintering bed by suction negative pressure control of wind boxes located below the pallet of the sintering machine and was combusted through the sintering bed in the combustion and melting zone present at the position described above. In this case, the amount of C-gas used was 3,000 m^3 (standard state)/hr.

The sintered ore yielded by the operation of the actual sintering machine had, as a whole, a tumbler index (TI) about 3% higher than that of a normal operation, a reduction-degradation index (RDI) about 3% higher than that of a normal operation, and a reducibility index (RI) about 4% higher than that of a normal operation. In addition, the productivity was increased by 0.03 $t/hr \cdot m^2$. Thus, the advantages of the present invention were confirmed.

The technique of the present invention is useful as a technique for producing a sintered ore used as a raw material for steelmaking, particularly for blast furnaces, although it can also be used as a technique for agglomerating other types of ores.

In the claims which follow and in the preceding description of the invention, except where the context requires otherwise due to express language or necessary implication, the word "comprise" or variations such as "comprises" or "comprising" is used in an inclusive sense, i.e. to specify the presence of the stated features but not to preclude the presence or addition of further features in various embodiments of the invention.

The Claims Defining the Invention are as Follows:

1. A method for producing sintered ore, comprising:

a charging step of charging a sintering raw material containing ore fines and a carbonaceous material onto a circulating pallet to form a sintering bed of the sintering raw material on the pallet;

an ignition step of igniting the carbonaceous material on a surface of the sintering bed;

a diluted gaseous fuel producing step of producing a diluted gaseous fuel having a concentration of a lower flammable limit concentration or less by supplying a gaseous fuel to air above the sintering bed at a flow speed at which a blow-off occurs to dilute the gaseous fuel;

and

a combustion step of combusting, in the sintering bed, the diluted gaseous fuel and the carbonaceous material contained in the sintering bed by sucking the diluted gaseous fuel and air into the sintering bed through a wind box disposed below the pallet, thereby forming a sinter cake.

2. The method for producing sintered ore according to Claim 1, wherein the flow speed at which a blow-off occurs is a speed exceeding the burning velocity of the gaseous fuel.

3. The method for producing sintered ore according to Claim 1, wherein the diluted gaseous fuel producing step comprises producing a diluted gaseous fuel having a concentration of a lower flammable limit concentration or less by ejecting a gaseous fuel into air above the sintering bed at a speed twice or more the burning velocity of the gaseous fuel to dilute the gaseous fuel.

4. The method for producing sintered ore according to

Claim 1, wherein the diluted gaseous fuel producing step comprises producing a diluted gaseous fuel having a concentration of a lower flammable limit or less by ejecting a gaseous fuel into air above the sintering bed at a speed twice or more the turbulent burning velocity of the gaseous fuel to dilute the gaseous fuel.

5. The method for producing sintered ore according to Claim 1, wherein the diluted gaseous fuel producing step comprises producing a diluted gaseous fuel having a concentration of a lower flammable limit concentration or less by ejecting a gaseous fuel into air above the sintering bed at a pressure of 300 mmAq to less than 40,000 mmAq with respect to an ambient pressure to dilute the gaseous fuel.

6. The method for producing ore according to Claim 1, wherein the diluted gaseous fuel producing step comprises ejecting a gaseous fuel from an outlet having an opening diameter of less than 3 mm into air above the sintering bed.

7. The method for producing sintered ore according to Claim 1, further comprising the step of adjusting at least one of the ultimate maximum temperature and the high-temperature-zone holding time in the sintering bed.

8. The method for producing sintered ore according to Claim 1, further comprising the step of adjusting the ultimate maximum temperature in the sintering bed by adjusting the amount of diluted gaseous fuel supplied or the concentration of the diluted gaseous fuel.

9. The method for producing sintered ore according to Claim 8, wherein the ultimate maximum temperature is 1,205°C to 1,380°C.

10. The method for producing sintered ore according to Claim 1, further comprising the step of adjusting the

ultimate maximum temperature in the sintering bed by adjusting the amount of carbonaceous material contained in the sintering raw material.

11. The method for producing sintered ore according to Claim 10, wherein the ultimate maximum temperature is 1,205°C to 1,380°C.

12. The method for producing sintered ore according to Claim 1, further comprising the step of adjusting the ultimate maximum temperature to 1,205°C to 1,380°C by adjusting at least one of the amount of diluted gaseous fuel supplied, the concentration of the diluted gaseous fuel, and the amount of carbonaceous material contained in the sintering raw material.

13. The method for producing sintered ore according to Claim 1, further comprising the step of adjusting the high-temperature-zone holding time in the sintering bed depending on the amount of diluted gaseous fuel supplied, the concentration of the diluted gaseous fuel, or the amount of carbonaceous material contained in the sintering raw material.

14. The method for producing sintered ore according to Claim 1, further comprising the step of adjusting the high-temperature-zone holding time in the sintering bed by adjusting the amount of diluted gaseous fuel supplied or the concentration of the diluted gaseous fuel depending on the amount of carbonaceous material contained in the sintering raw material.

15. The method for producing sintered ore according to Claim 1, wherein the combustion step comprises combusting the diluted gaseous fuel so that at least a portion of the diluted gaseous fuel introduced from above the sintering bed reaches a combustion and melting zone in the sintering bed while remaining unburned.

16. The method for producing sintered ore according to Claim 1, further comprising the step of adjusting the form of a combustion and melting zone in the sintering bed by combusting the diluted gaseous fuel introduced from above the sintering bed.

17. The method for producing sintered ore according to Claim 16, wherein the step of adjusting the form of the combustion and melting zone comprises adjusting the thickness of the combustion and melting zone in a height direction and/or the width of the combustion and melting zone in a movement direction of the pallet by combusting the diluted gaseous fuel introduced from above the sintering bed.

18. The method for producing sintered ore according to Claim 1, wherein the combustion step comprises combusting the diluted gaseous fuel in the sintering bed to extend the high-temperature-zone holding time of a combustion and melting zone, thereby adjusting the cold strength of sintered ore.

19. The method for producing sintered ore according to Claim 1, further comprising the step of adjusting a position where the diluted gaseous fuel is introduced into the sintering bed.

20. The method for producing sintered ore according to Claim 1, wherein the combustion step comprises combusting the diluted gaseous fuel in the sintering bed by sucking the diluted gaseous fuel into the sintering bed at a position downstream of an ignition furnace.

21. The method for producing sintered ore according to Claim 1, wherein the combustion step comprises combusting the diluted gaseous fuel in the sintering bed by sucking the diluted gaseous fuel into the sintering bed during a period of time after formation of a sinter cake in a surface layer of the sintering bed until burn-through.

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22. The method for producing sintered ore according to Claim 1, wherein the combustion step comprises combusting the diluted gaseous fuel in the sintering bed by sucking the diluted gaseous fuel into the sintering bed in a region where the thickness of a combustion and melting zone is 15 mm or more.

23. The method for producing sintered ore according to Claim 1, wherein the combustion step comprises combusting the diluted gaseous fuel in the sintering bed by sucking the diluted gaseous fuel into the sintering bed downstream of a position where a combustion front has reached 100 mm below a surface of the sintering bed.

24. The method for producing sintered ore according to Claim 1, wherein the combustion step comprises combusting the diluted gaseous fuel in the sintering bed by sucking the diluted gaseous fuel into the sintering bed near both sidewalls.

25. The method for producing sintered ore according to Claim 1, wherein the diluted gaseous fuel is a flammable gas diluted to a concentration of 75% to 2% of the lower flammable limit concentration.

26. The method for producing sintered ore according to Claim 1, wherein the diluted gaseous fuel is a flammable gas diluted to a concentration of 60% to 2% of the lower flammable limit concentration.

27. The method for producing sintered ore according to Claim 1, wherein the diluted gaseous fuel is a flammable gas diluted to a concentration of 25% to 2% of the lower flammable limit concentration.

28. The method for producing sintered ore according to Claim 1, wherein the gaseous fuel is a flammable gas selected from the group consisting of blast furnace gas,

coke oven gas, a mixture of blast furnace gas and coke oven gas, town gas, natural gas, methane gas, ethane gas, propane gas, and a mixture thereof.

29. The method for producing sintered ore according to Claim 1, wherein the gaseous fuel is a gas having a CO content of 50 ppm by mass or less.

30. The method for producing sintered ore according to Claim 1, wherein the gaseous fuel is a vapor of a liquid fuel having an ignition temperature in vapor phase higher than the temperature of a surface layer of the sintering bed.

31. The method for producing sintered ore according to Claim 30, wherein the liquid fuel is one selected from the group consisting of alcohols, ethers, petroleum oils, and other hydrocarbon compounds.

32. A sintering machine comprising:

a circulating pallet;

a sintering raw material supply unit for charging a sintering raw material containing ore fines and a carbonaceous material onto the circulating pallet to form a sintering bed;

an ignition furnace for igniting the carbonaceous material in the sintering raw material;

a wind box disposed below the pallet; and

a gaseous fuel supply unit, disposed downstream of the ignition furnace in an advancing direction of the pallet, for ejecting a gaseous fuel into air above the sintering bed so as to mix the gaseous fuel with air,

the gaseous fuel supply unit comprising gaseous fuel supply pipes and ejection means for ejecting the gaseous fuel provided in the pipes, the ejection means including one selected from the group consisting of slits, openings, and nozzles, the ejection means having an opening diameter of 0.5 to 3 mm.

33. The sintering machine according to Claim 32, wherein the gaseous fuel supply unit ejects a gaseous fuel into air above the sintering bed so as to mix the gaseous fuel with air, thereby preparing a diluted gaseous fuel having a concentration of a lower flammable limit concentration or less.

34. The sintering machine according to Claim 32, wherein the gaseous fuel supply unit comprises a plurality of gaseous fuel supply pipes disposed along a width direction of the pallet and ejection means, for ejecting the gaseous fuel, provided in the pipes and including one selected from the group consisting of slits, openings, and nozzles.

35. The sintering machine according to Claim 32, wherein the gaseous fuel supply unit comprises a plurality of gaseous fuel supply pipes disposed along the movement direction of the pallet and ejection means, for ejecting the gaseous fuel, provided in the pipes and including one selected from the group consisting of slits, openings, and nozzles.

36. The sintering machine according to Claim 32, wherein the gaseous fuel supply unit includes a control device for controlling the amount of gaseous fuel supplied in a width direction of the pallet.

37. The sintering machine according to Claim 32, wherein the gaseous fuel supply unit includes a fuel concentration control device for maintaining a constant fuel concentration per amount of suction air by supplying a larger amount of fuel to a portion having a higher suction speed and supplying a smaller amount of fuel to a portion having a lower suction speed, depending on the distribution of the suction speed in a width direction of the pallet.

38. The sintering machine according to Claim 32, wherein the gaseous fuel supply unit is a gaseous fuel supply unit for ejecting the gaseous fuel downward toward the sintering bed.

39. The sintering machine according to Claim 32, wherein the gaseous fuel supply unit is a gaseous fuel supply unit for ejecting the gaseous fuel in parallel with a surface of the sintering bed.

40. The sintering machine according to Claim 32, wherein the gaseous fuel supply unit is a gaseous fuel supply unit for ejecting the gaseous fuel toward a reflective plate.

41. The sintering machine according to Claim 32, wherein the gaseous fuel supply unit comprises gaseous fuel supply pipes and gas ejection slits, openings, or nozzles provided in the gaseous fuel supply pipes, the slits, openings, or nozzles being directed toward a surface of the sintering bed so as to diverge in the range of ±90° with respect to a perpendicular direction.

42. The sintering machine according to Claim 32, wherein the gaseous fuel supply unit comprises gaseous fuel supply pipes rotatable about axes thereof.

43. The sintering machine according to Claim 32, wherein the gaseous fuel supply unit has gaseous fuel outlets at a height of 300 mm or more above a surface of the sintering bed.

44. The sintering machine according to Claim 32, wherein the gaseous fuel supply unit includes a lifting and lowering mechanism capable of adjusting a position where the gaseous fuel is ejected to a height of 300 mm or more above a surface of the sintering bed.

45. The sintering machine according to Claim 32, wherein the gaseous fuel supply unit is a gaseous fuel supply unit

disposed at a position between a position where a combustion front has propagated below a surface of the sintering bed and a burn-through position in an advancing direction of the pallet.

46. The sintering machine according to Claim 32, wherein the gaseous fuel supply unit is a gaseous fuel supply unit disposed near sidewalls.

47. The method for producing sintered ore according to Claim 1, or the sintering machine according to Claim 32, substantially as herein described with reference to the accompanying Figures or any one of the Examples.

FIG. 1

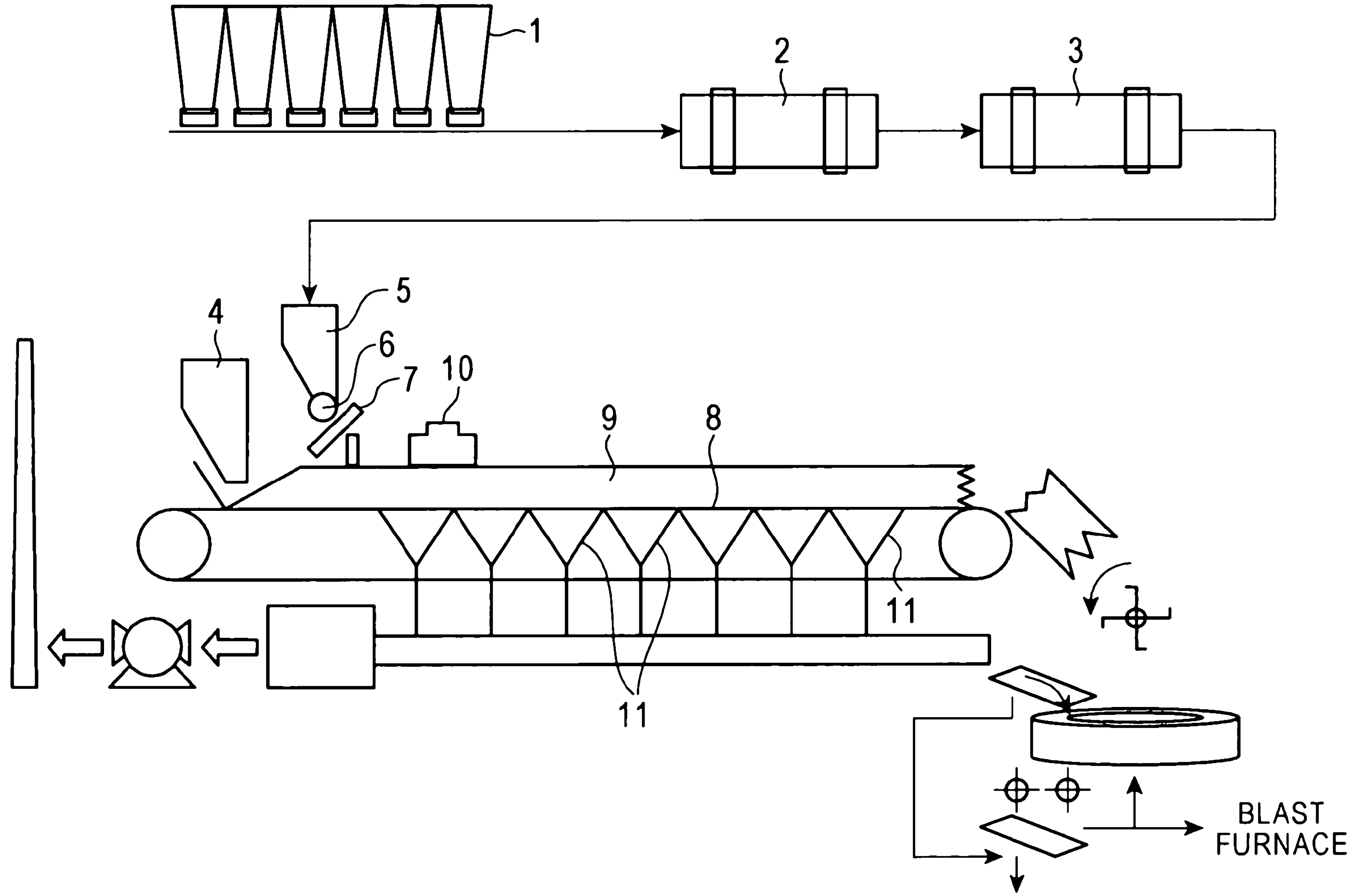
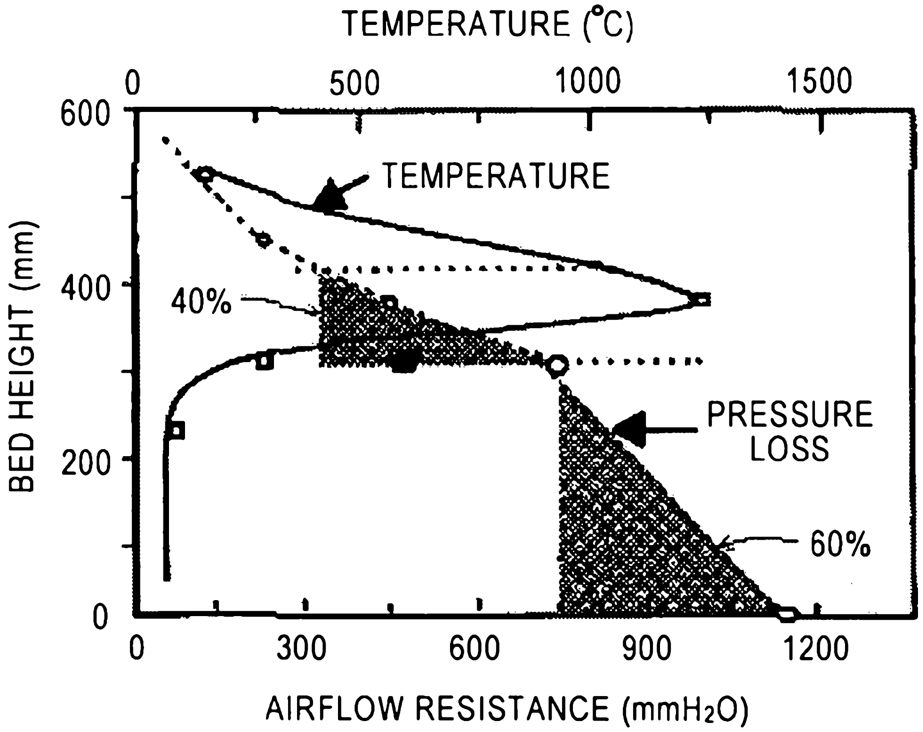
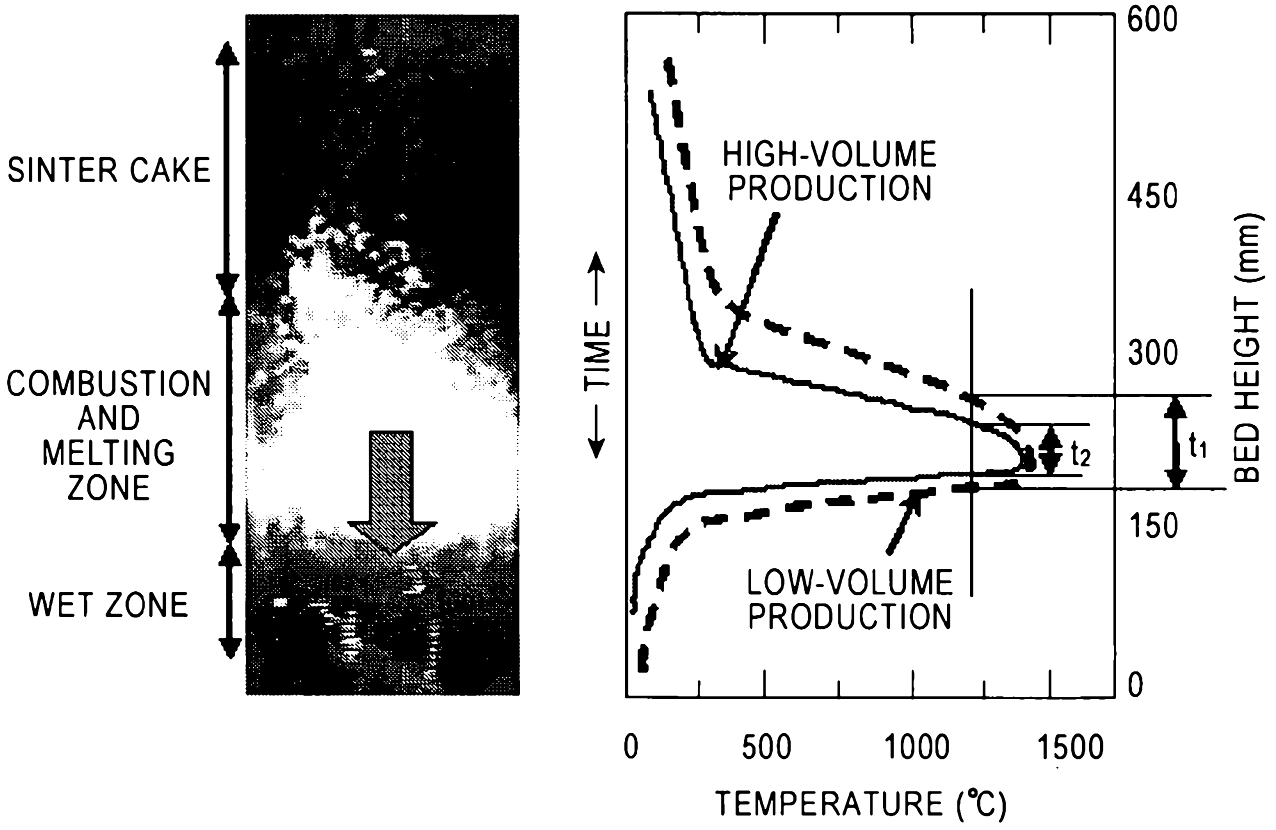


FIG. 2



TEMPERATURE (℃)
0
500
1000
1500
600
400
200
0
BED HEIGHT (mm)
TEMPERATURE
40%
PRESSURE LOSS
60%
0
300
600
900
1200
AIRFLOW RESISTANCE (mmH2O)

FIG. 3



SINTER CAKE
COMBUSTION AND MELTING ZONE
WET ZONE
← TIME →
HIGH-VOLUME PRODUCTION
LOW-VOLUME PRODUCTION
t2
t1
600
450
300
150
0
BED HEIGHT (mm)
0
500
1000
1500
TEMPERATURE (℃)

FIG. 4

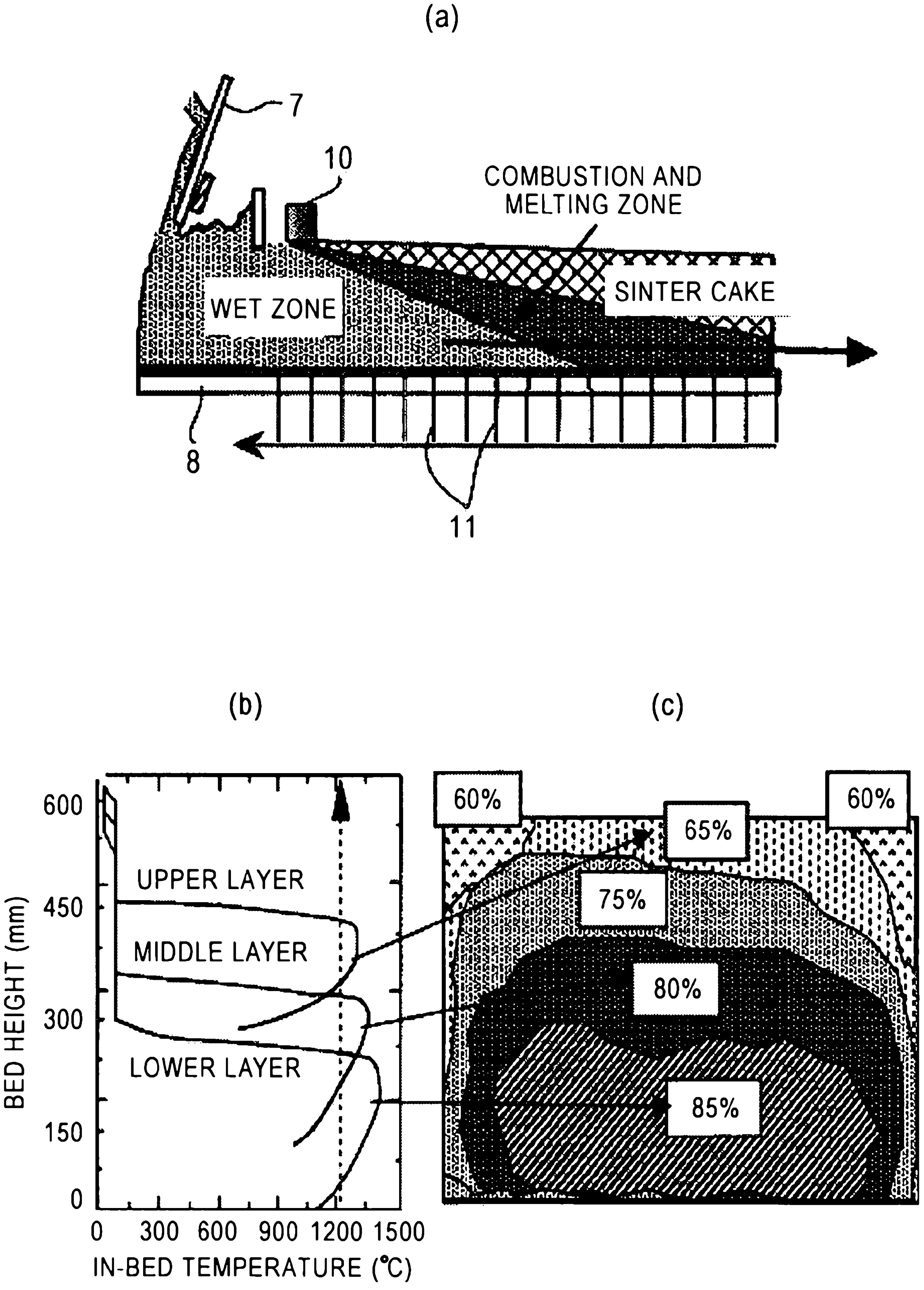
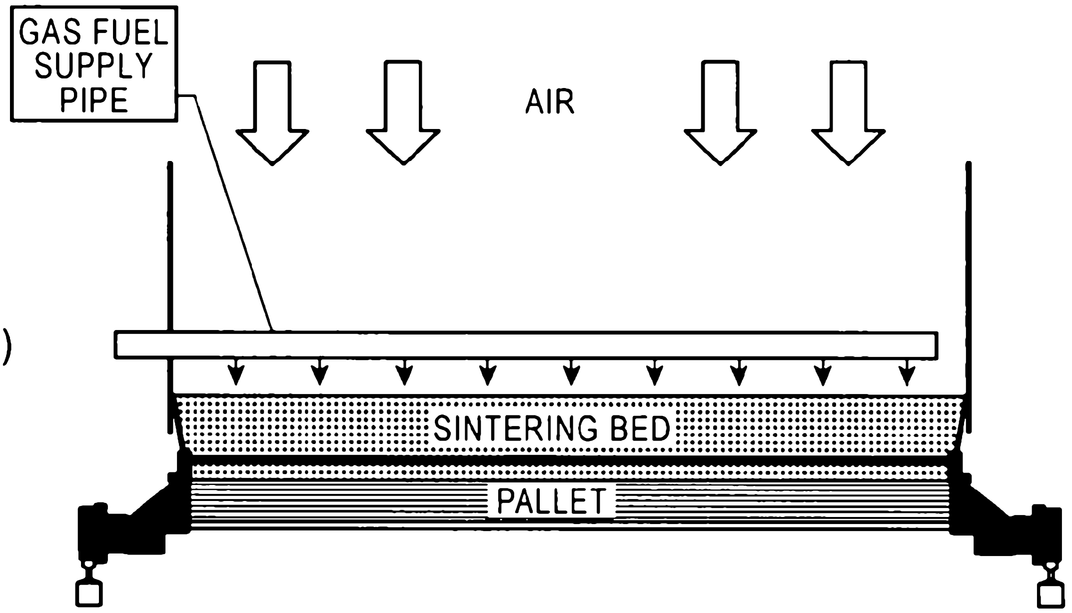

(a)
7
10
COMBUSTION AND
MELTING ZONE
WET ZONE
SINTER CAKE
8
11
(b)
(c)
600
450
300
150
0
BED HEIGHT (mm)
UPPER LAYER
MIDDLE LAYER
LOWER LAYER
0
300
600
900
1200
1500
IN-BED TEMPERATURE (℃)
60%
65%
60%
75%
80%
85%

FIG. 5

(a)


GAS FUEL SUPPLY PIPE
AIR
SINTERING BED
PALLET

(b)

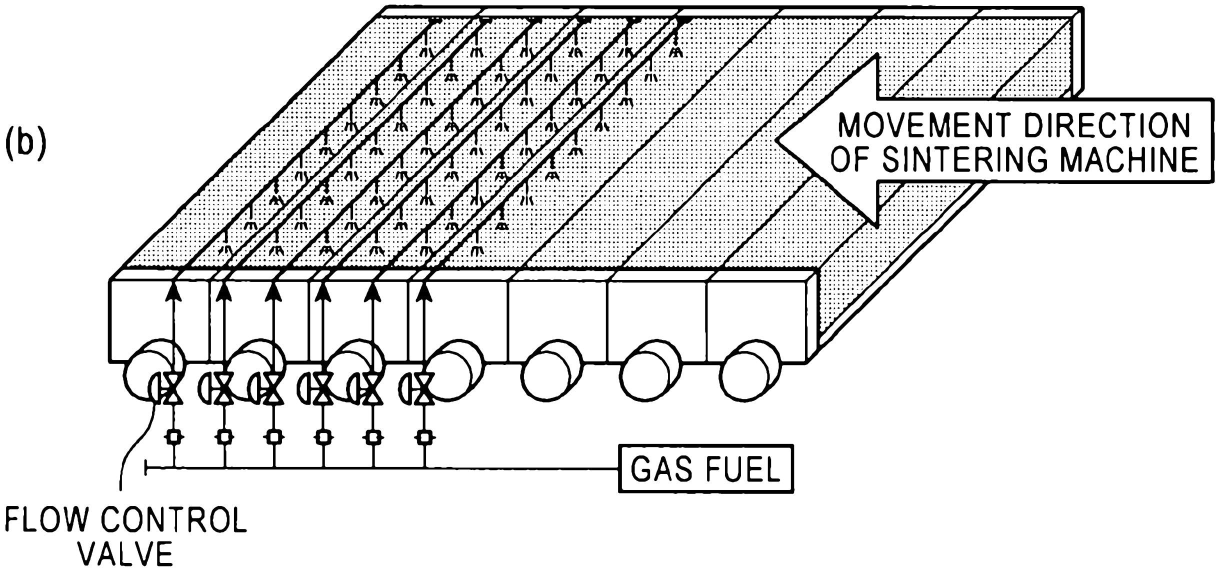

MOVEMENT DIRECTION OF SINTERING MACHINE
GAS FUEL
FLOW CONTROL VALVE

FIG. 6

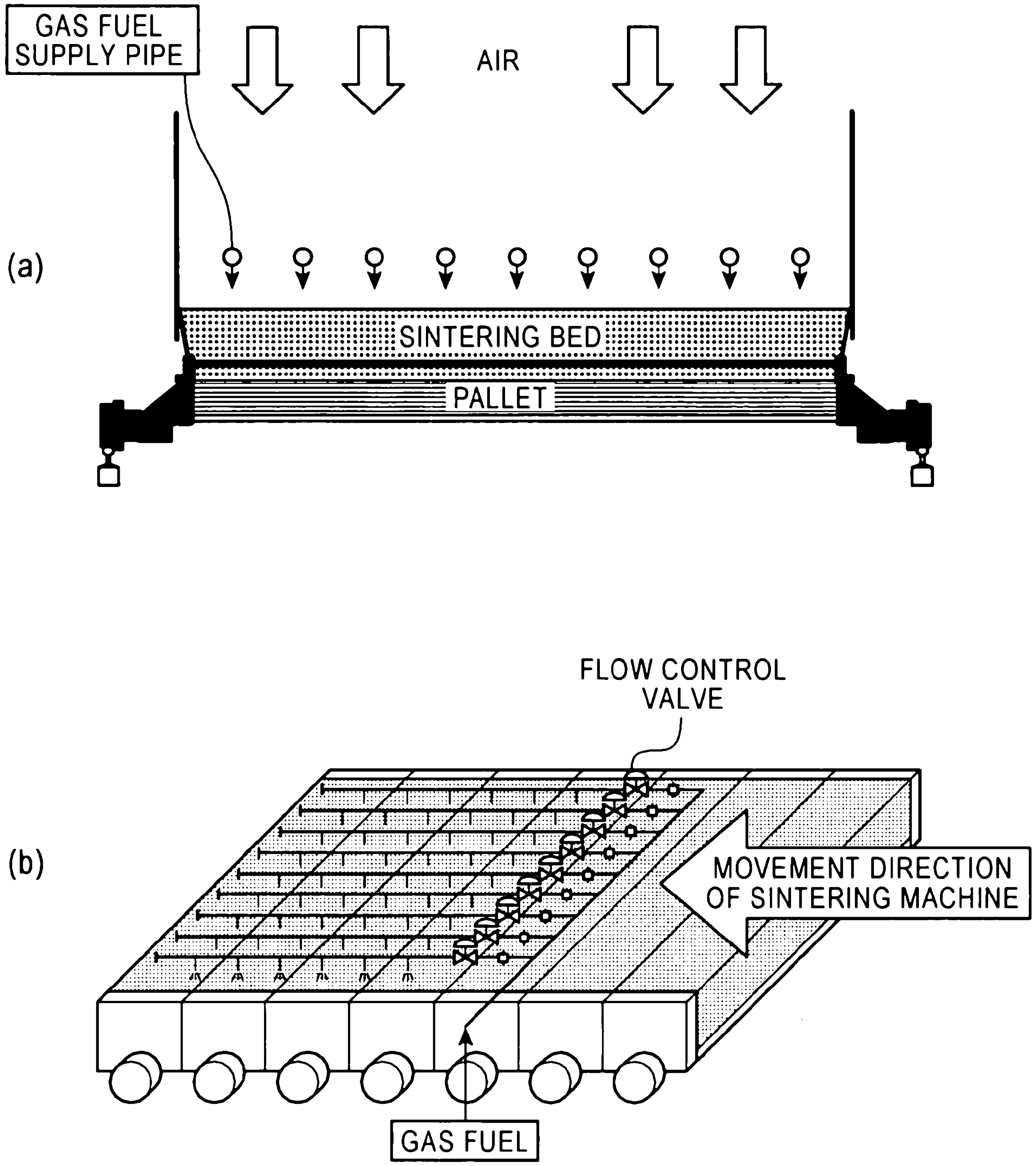

GAS FUEL SUPPLY PIPE
AIR
(a)
SINTERING BED
PALLET
(b)
FLOW CONTROL VALVE
MOVEMENT DIRECTION OF SINTERING MACHINE
GAS FUEL

FIG. 7

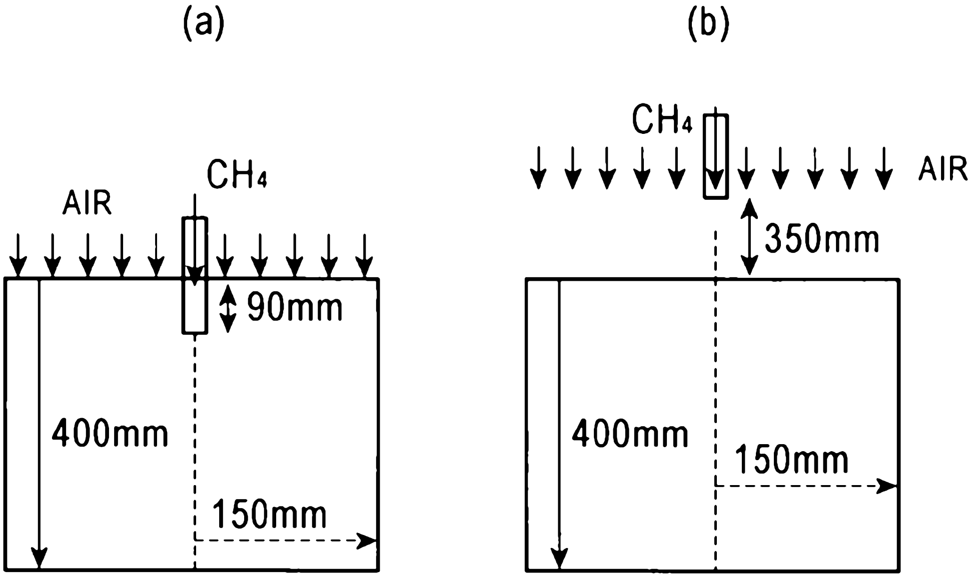


FIG. 8

GAS INJECTION DIRECTION: VERTICALLY DOWNWARD

(CROSS-SECTIONAL VIEW)

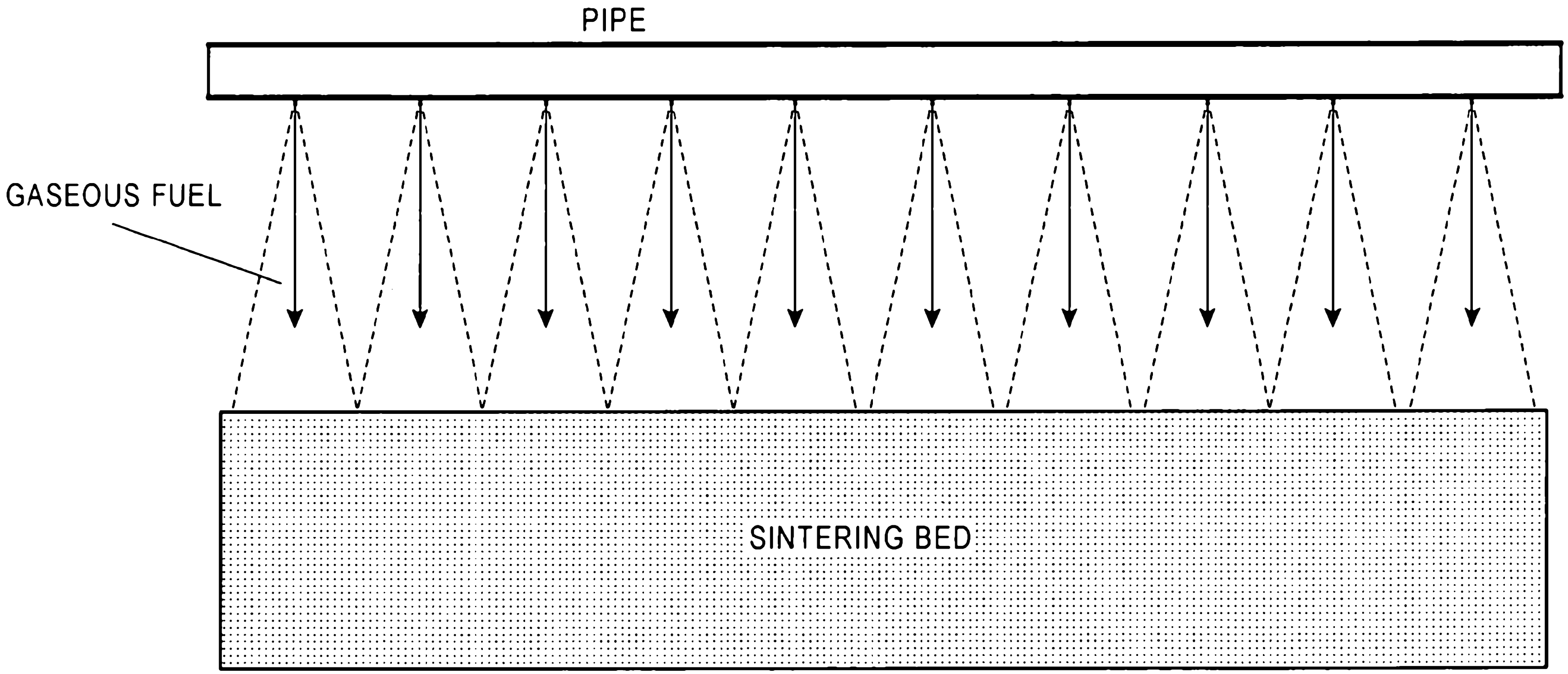


FIG. 9

GAS INJECTION DIRECTION: HORIZONTAL DIRECTION

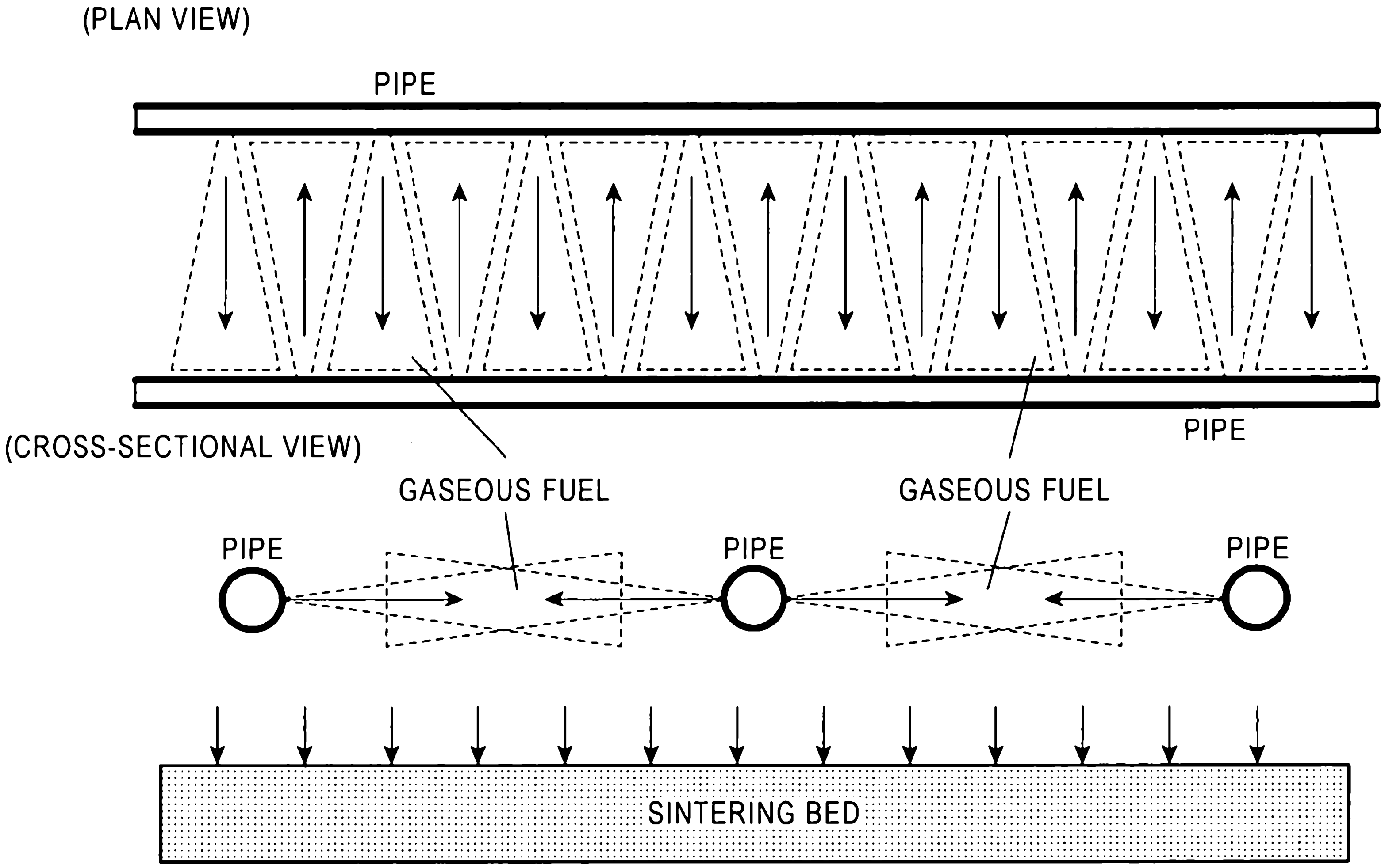


FIG. 10

GAS INJECTION DIRECTION : DIAGONALLY UPWARD (MIXED BY BAFFLE PLATES)

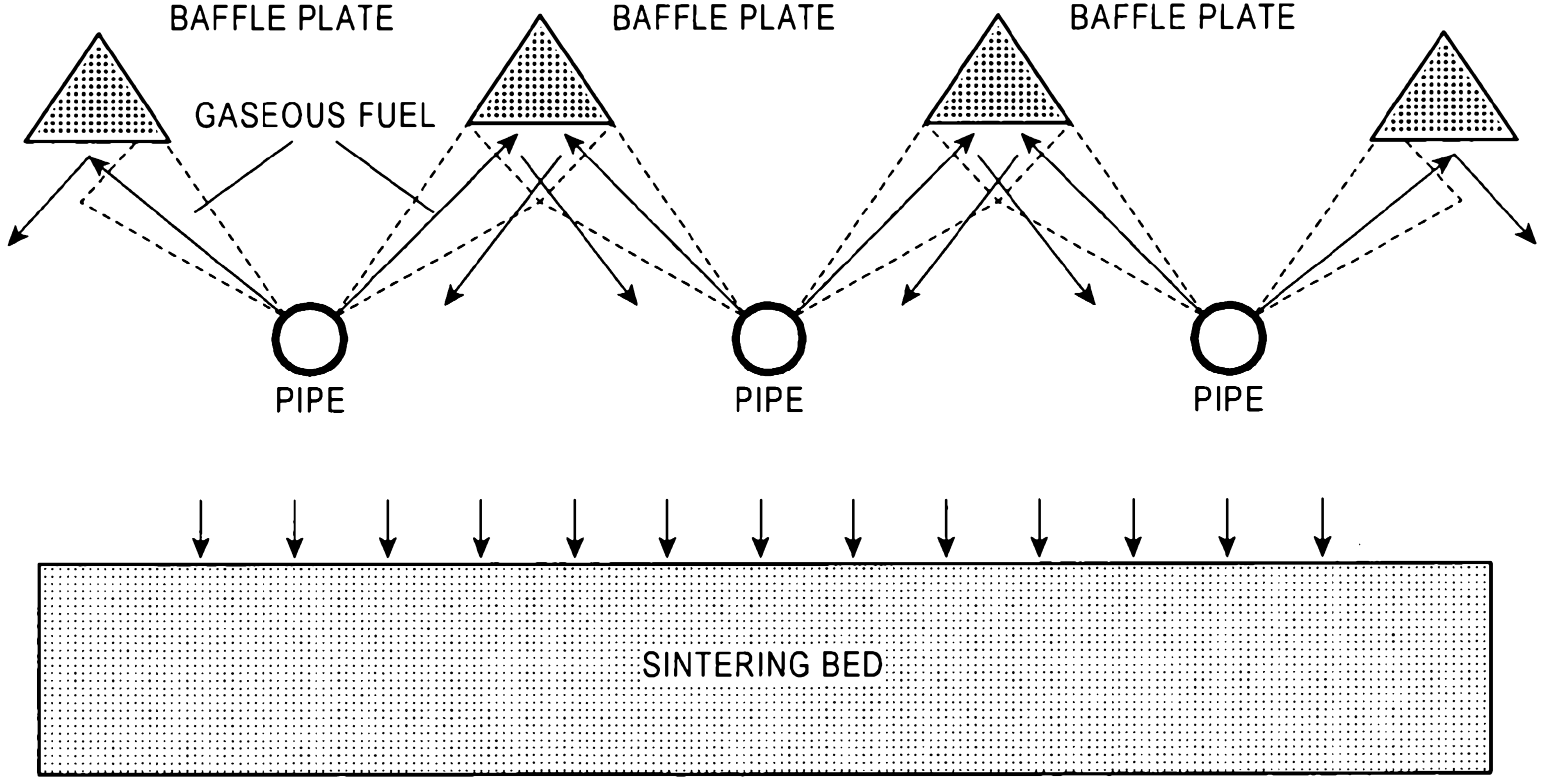


FIG. 11

GAS INJECTION DIRECTION : DIVERGING DOWNWARD (MULTIPLE INJECTION)

(CROSS-SECTIONAL VIEW)

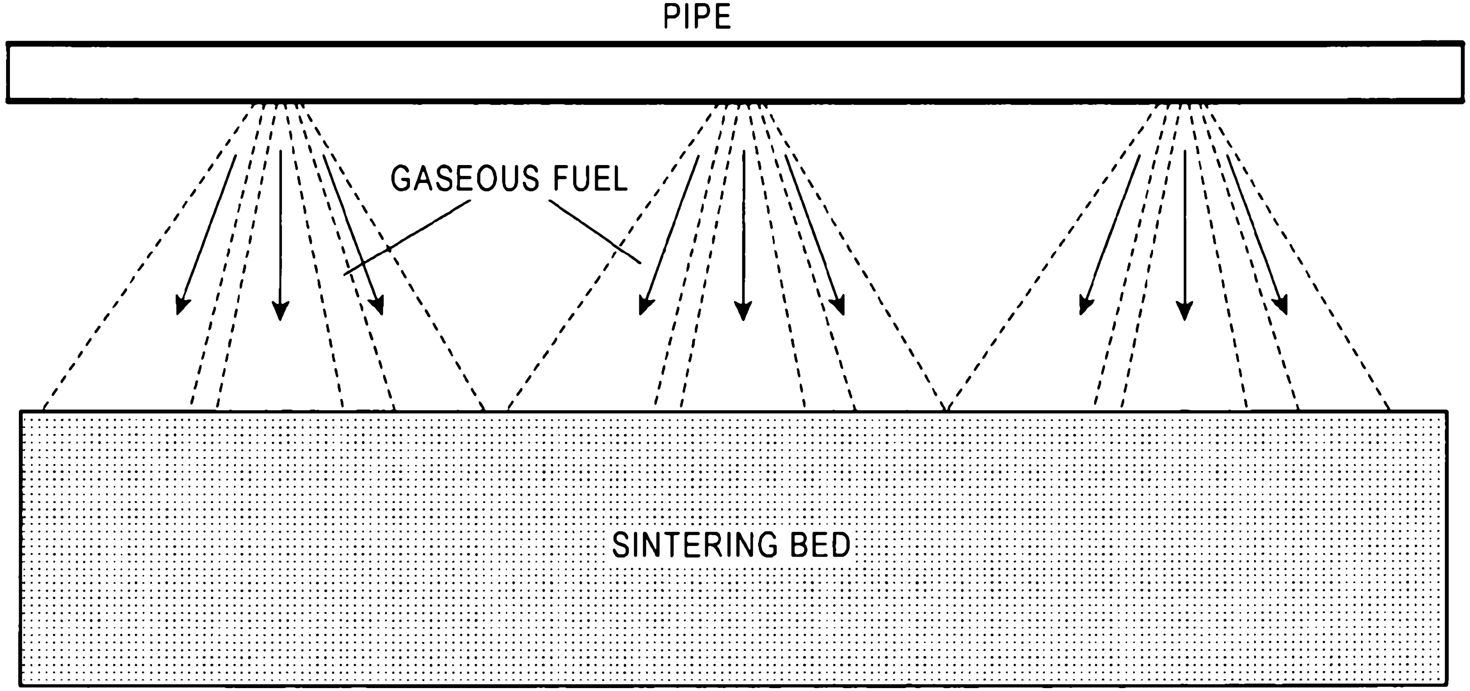


FIG. 12

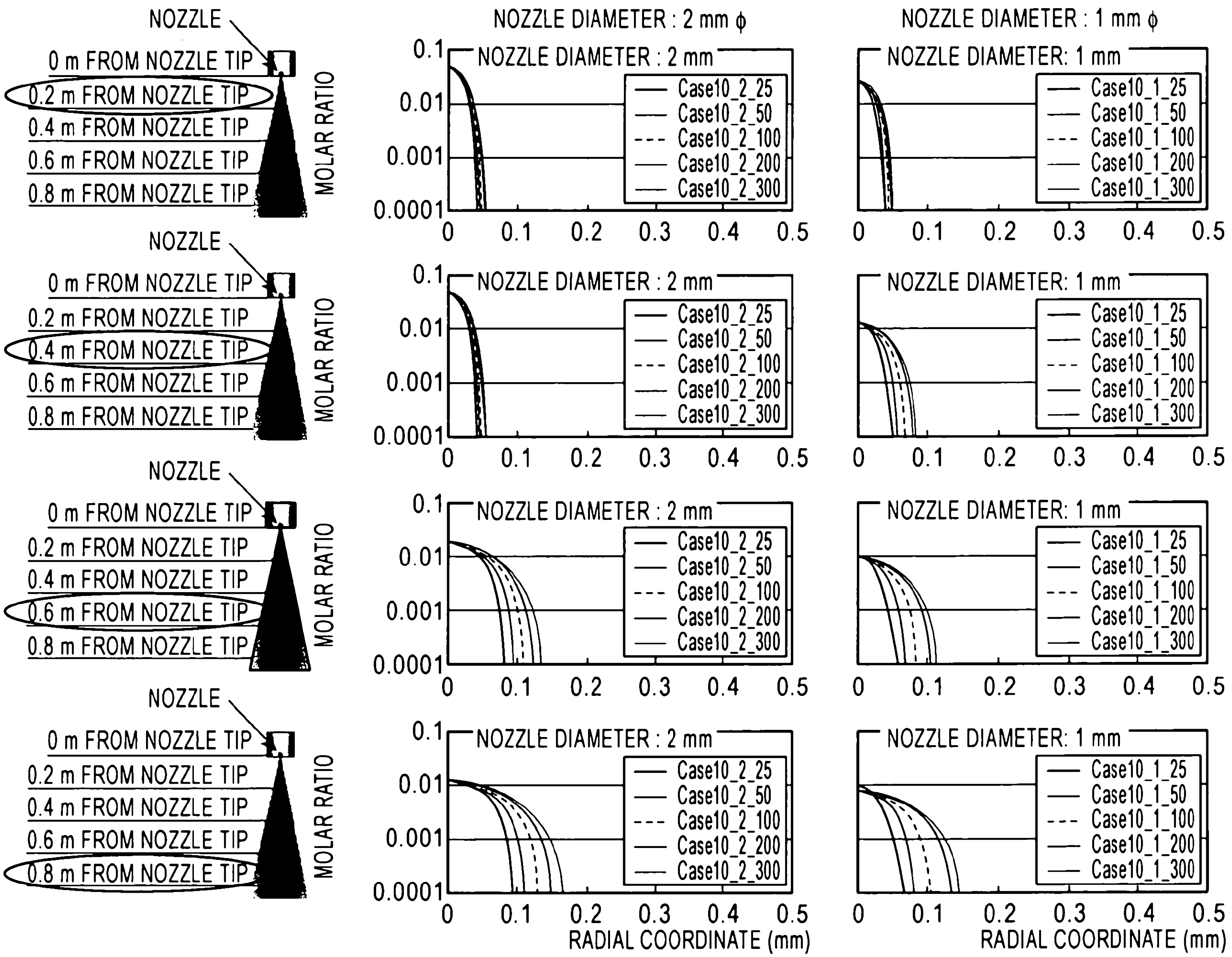

NOZZLE
0 m FROM NOZZLE TIP
0.2 m FROM NOZZLE TIP
0.4 m FROM NOZZLE TIP
0.6 m FROM NOZZLE TIP
0.8 m FROM NOZZLE TIP
MOLAR RATIO
NOZZLE DIAMETER : 2 mm ϕ
NOZZLE DIAMETER : 1 mm ϕ
NOZZLE DIAMETER : 2 mm
NOZZLE DIAMETER: 1 mm
Case10_2_25
Case10_2_50
Case10_2_100
Case10_2_200
Case10_2_300
Case10_1_25
Case10_1_50
Case10_1_100
Case10_1_200
Case10_1_300
0.1
0.01
0.001
0.0001
0
0.1
0.2
0.3
0.4
0.5
RADIAL COORDINATE (mm)

FIG. 13

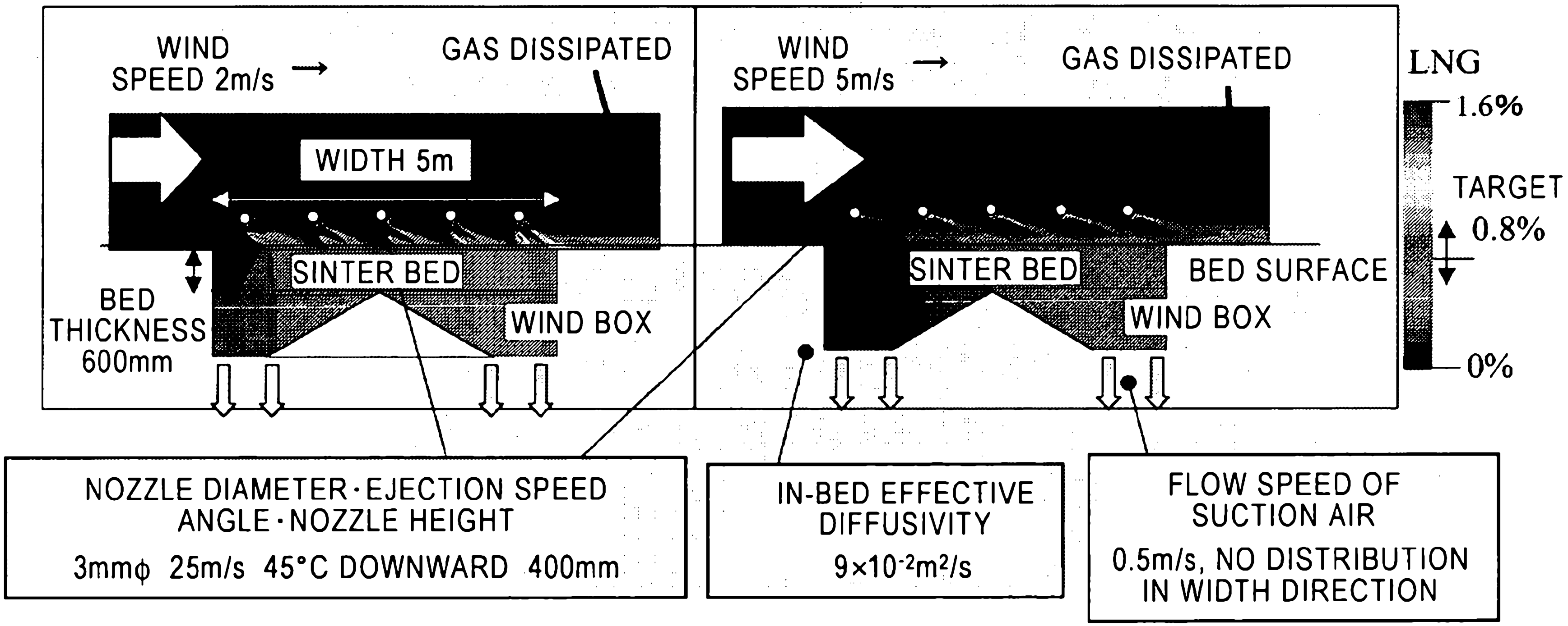

WIND SPEED 2m/s →
GAS DISSIPATED
WIDTH 5m
SINTER BED
BED THICKNESS 600mm
WIND BOX
WIND SPEED 5m/s →
GAS DISSIPATED
SINTER BED
BED SURFACE
WIND BOX
LNG
1.6%
TARGET
0.8%
0%
NOZZLE DIAMETER·EJECTION SPEED ANGLE·NOZZLE HEIGHT
3mmφ 25m/s 45°C DOWNWARD 400mm
IN-BED EFFECTIVE DIFFUSIVITY
9×10-2m2/s
FLOW SPEED OF SUCTION AIR
0.5m/s, NO DISTRIBUTION IN WIDTH DIRECTION

FIG. 14

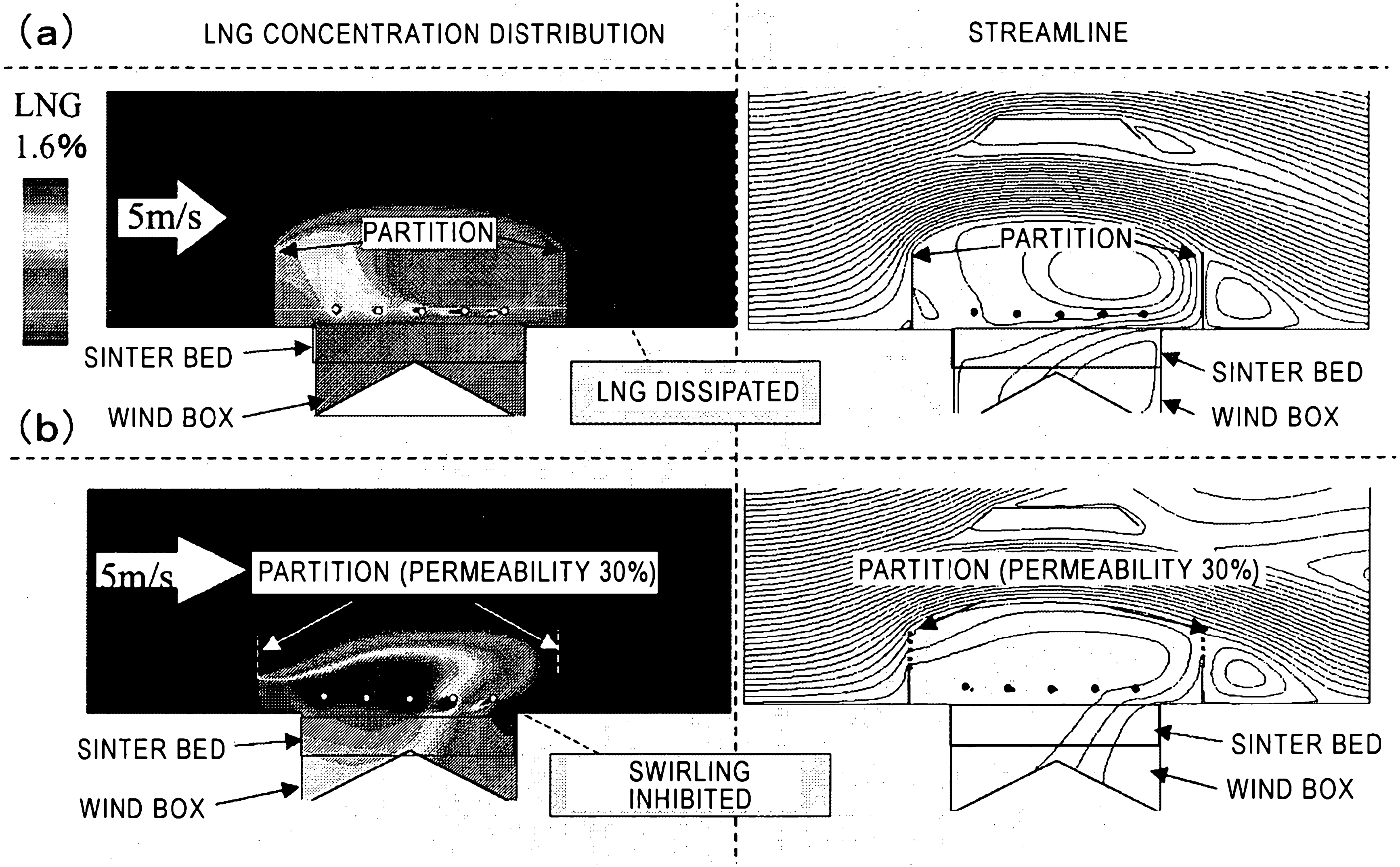

(a)
LNG CONCENTRATION DISTRIBUTION
STREAMLINE
LNG
1.6%
5m/s
PARTITION
SINTER BED
WIND BOX
LNG DISSIPATED
PARTITION
SINTER BED
WIND BOX
(b)
5m/s
PARTITION (PERMEABILITY 30%)
SINTER BED
WIND BOX
SWIRLING INHIBITED
PARTITION (PERMEABILITY 30%)
SINTER BED
WIND BOX

FIG. 15

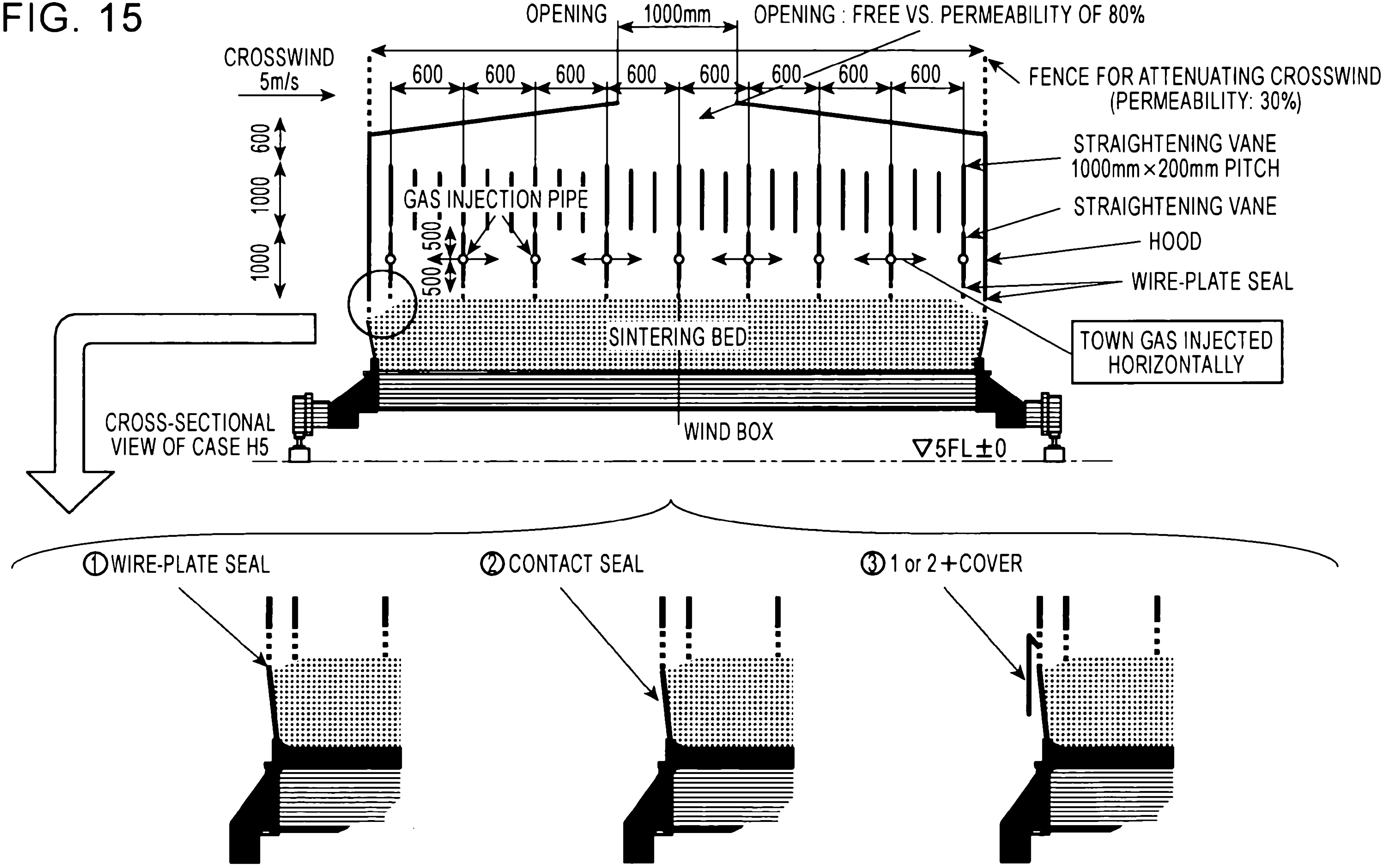

OPENING
1000mm
OPENING : FREE VS. PERMEABILITY OF 80%
CROSSWIND
5m/s
600
600
600
600
600
600
600
600
FENCE FOR ATTENUATING CROSSWIND
(PERMEABILITY: 30%)
600
1000
1000
STRAIGHTENING VANE
1000mm×200mm PITCH
GAS INJECTION PIPE
STRAIGHTENING VANE
500
500
HOOD
WIRE-PLATE SEAL
SINTERING BED
TOWN GAS INJECTED
HORIZONTALLY
CROSS-SECTIONAL
VIEW OF CASE H5
WIND BOX
∇5FL±0
①WIRE-PLATE SEAL
②CONTACT SEAL
③1 or 2+COVER

FIG. 16

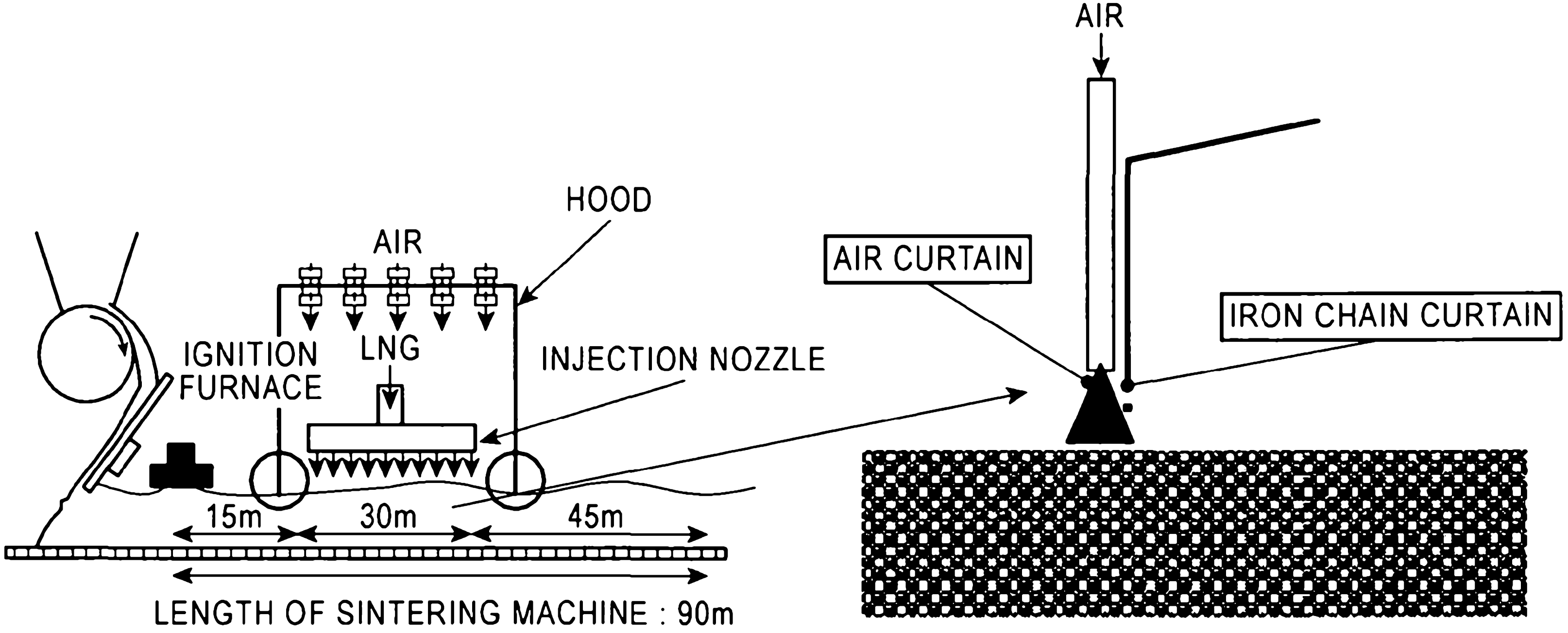

AIR
HOOD
AIR
IGNITION FURNACE
LNG
INJECTION NOZZLE
AIR CURTAIN
IRON CHAIN CURTAIN
15m
30m
45m
LENGTH OF SINTERING MACHINE : 90m

FIG. 17

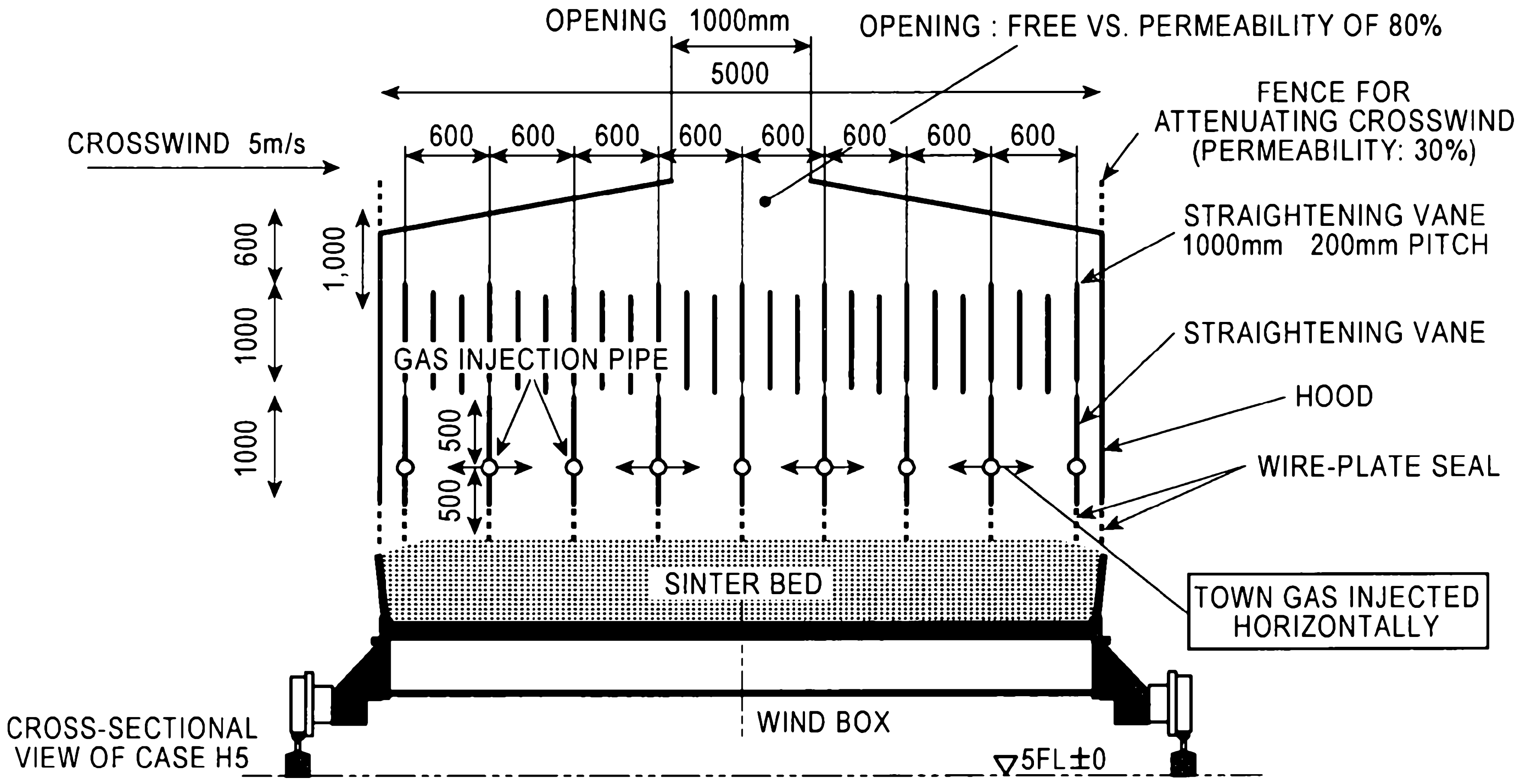

OPENING 1000mm
OPENING : FREE VS. PERMEABILITY OF 80%
5000
FENCE FOR
ATTENUATING CROSSWIND
(PERMEABILITY: 30%)
CROSSWIND 5m/s
600
600
600
600
600
600
600
600
STRAIGHTENING VANE
1000mm 200mm PITCH
600
1000
1000
1,000
STRAIGHTENING VANE
GAS INJECTION PIPE
HOOD
500
500
WIRE-PLATE SEAL
SINTER BED
TOWN GAS INJECTED
HORIZONTALLY
WIND BOX
CROSS-SECTIONAL
VIEW OF CASE H5
▽5FL±0

FIG. 18

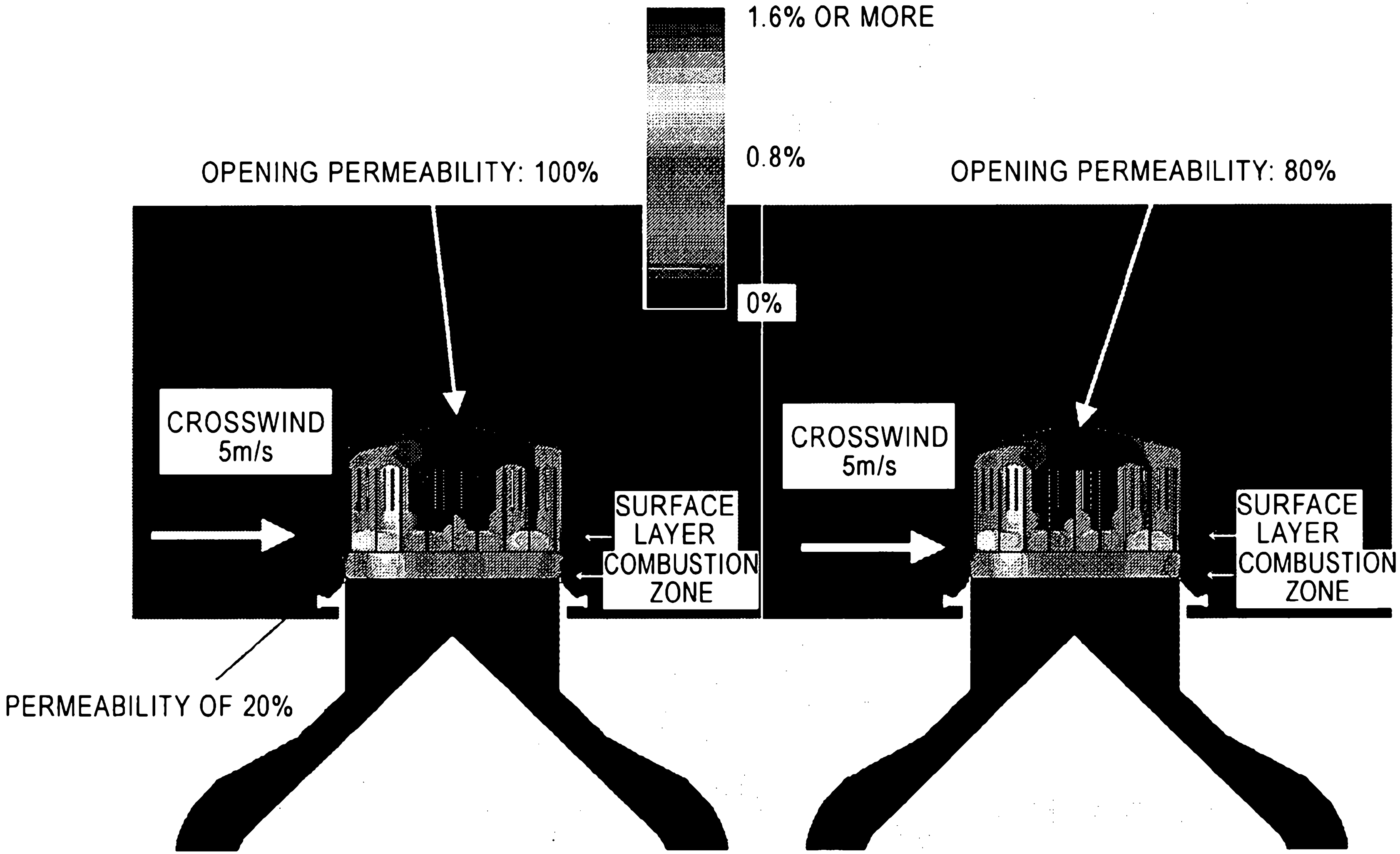

1.6% OR MORE
0.8%
0%
OPENING PERMEABILITY: 100%
OPENING PERMEABILITY: 80%
CROSSWIND
5m/s
CROSSWIND
5m/s
SURFACE
LAYER
COMBUSTION
ZONE
SURFACE
LAYER
COMBUSTION
ZONE
PERMEABILITY OF 20%

FIG. 19

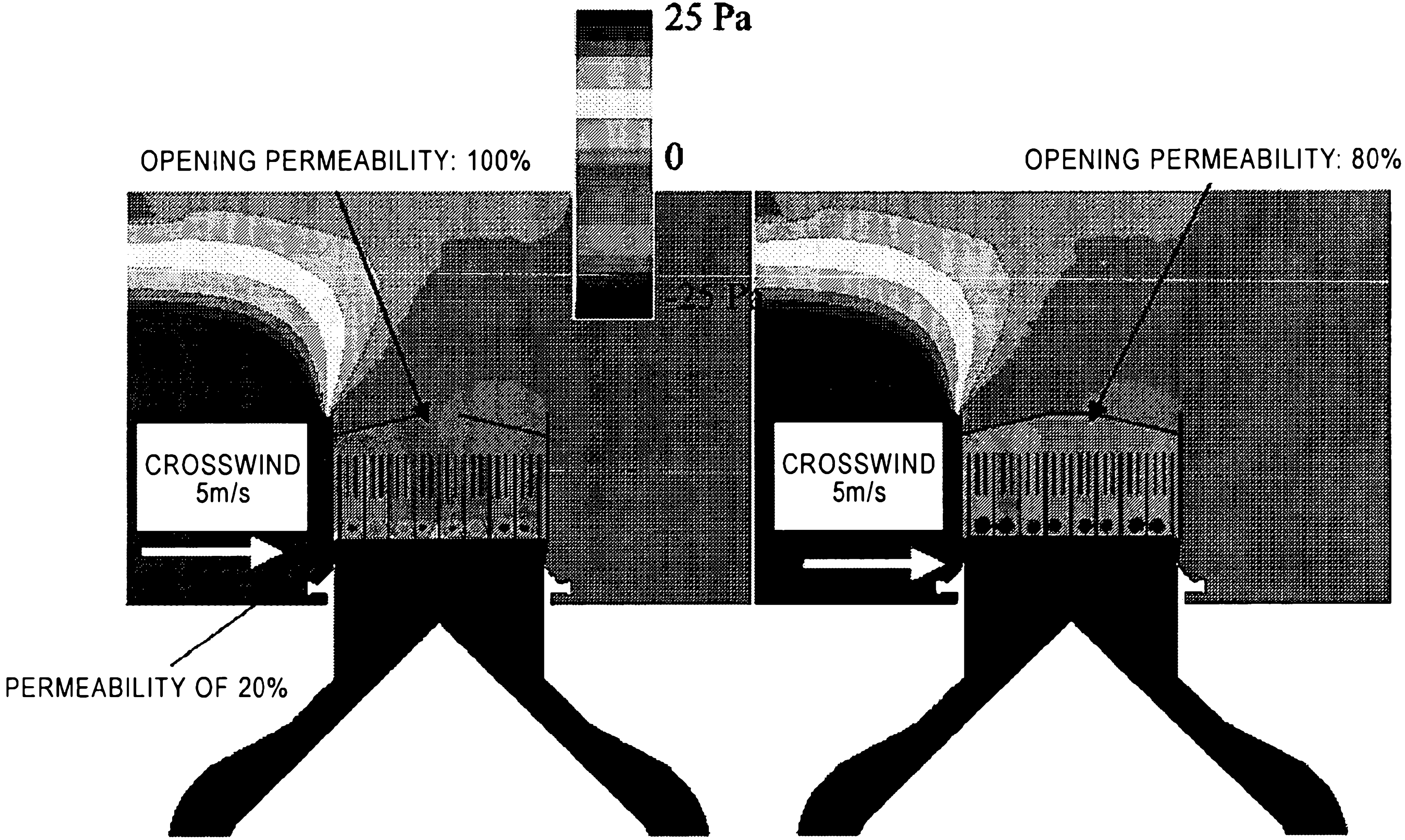

25 Pa
0
25 P
OPENING PERMEABILITY: 100%
OPENING PERMEABILITY: 80%
CROSSWIND
5m/s
CROSSWIND
5m/s
PERMEABILITY OF 20%

FIG. 20

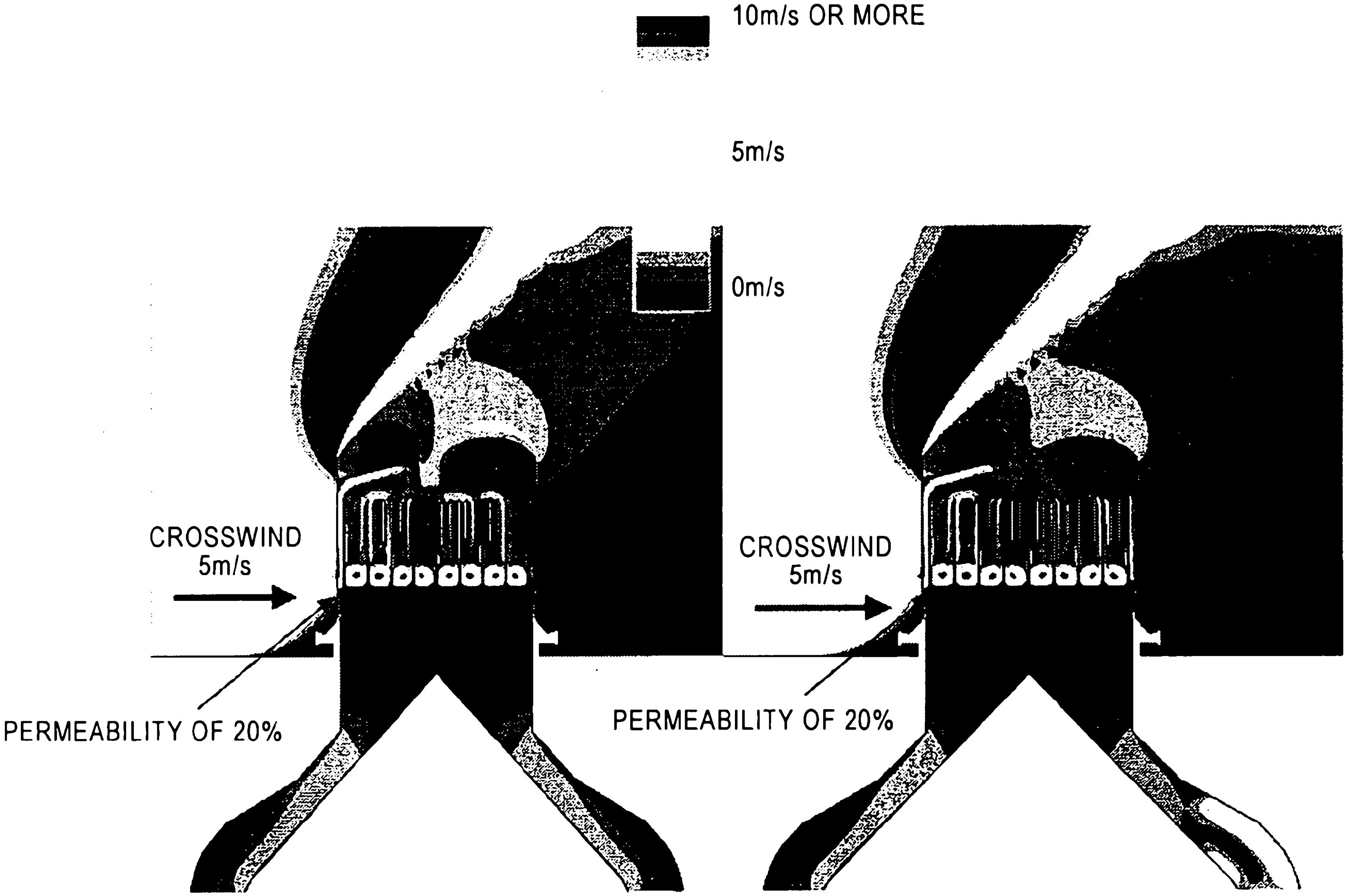

10m/s OR MORE
5m/s
0m/s
CROSSWIND
5m/s
PERMEABILITY OF 20%
CROSSWIND
5m/s
PERMEABILITY OF 20%

FIG. 21

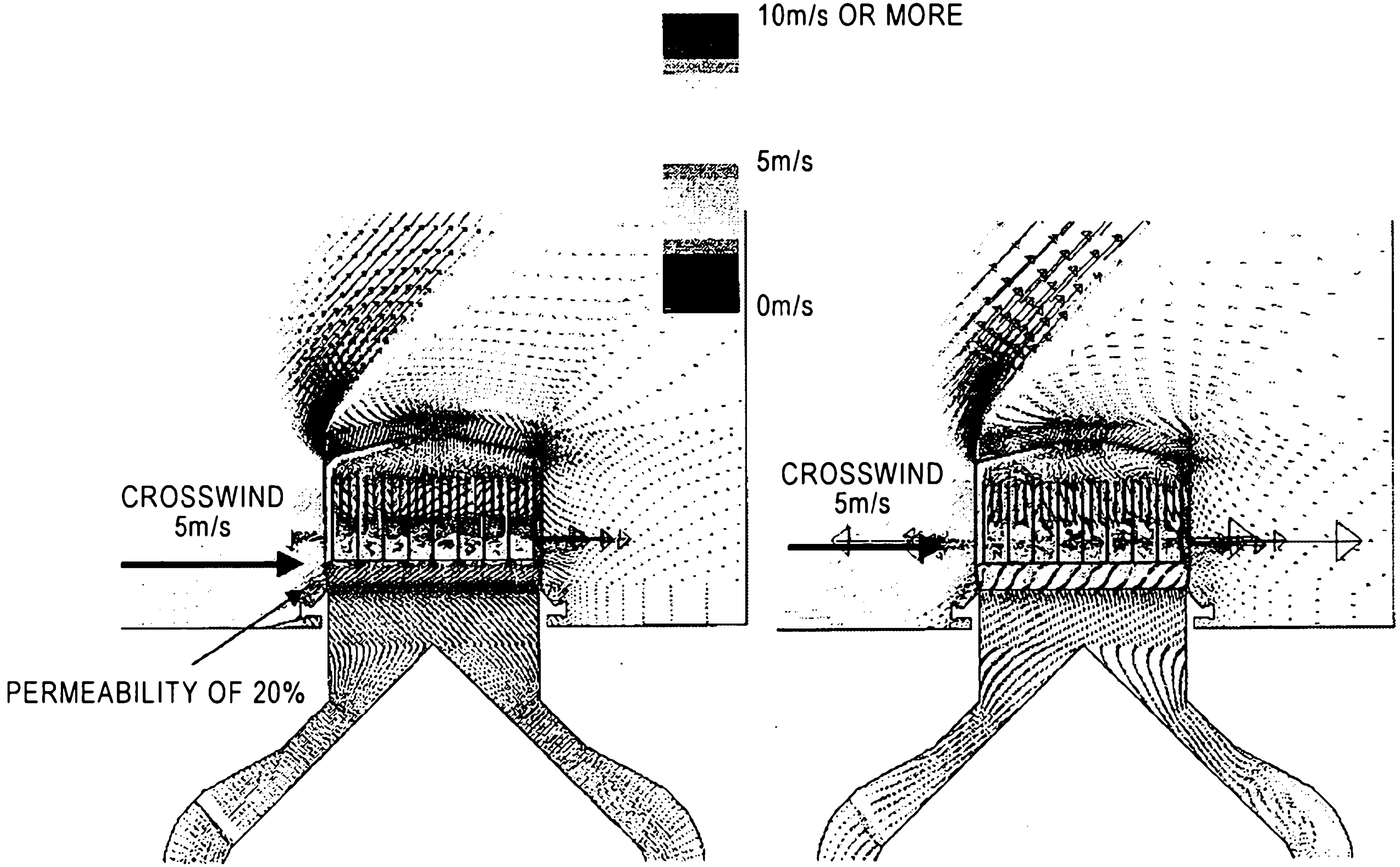

10m/s OR MORE
5m/s
0m/s
CROSSWIND
5m/s
PERMEABILITY OF 20%
CROSSWIND
5m/s

FIG. 22

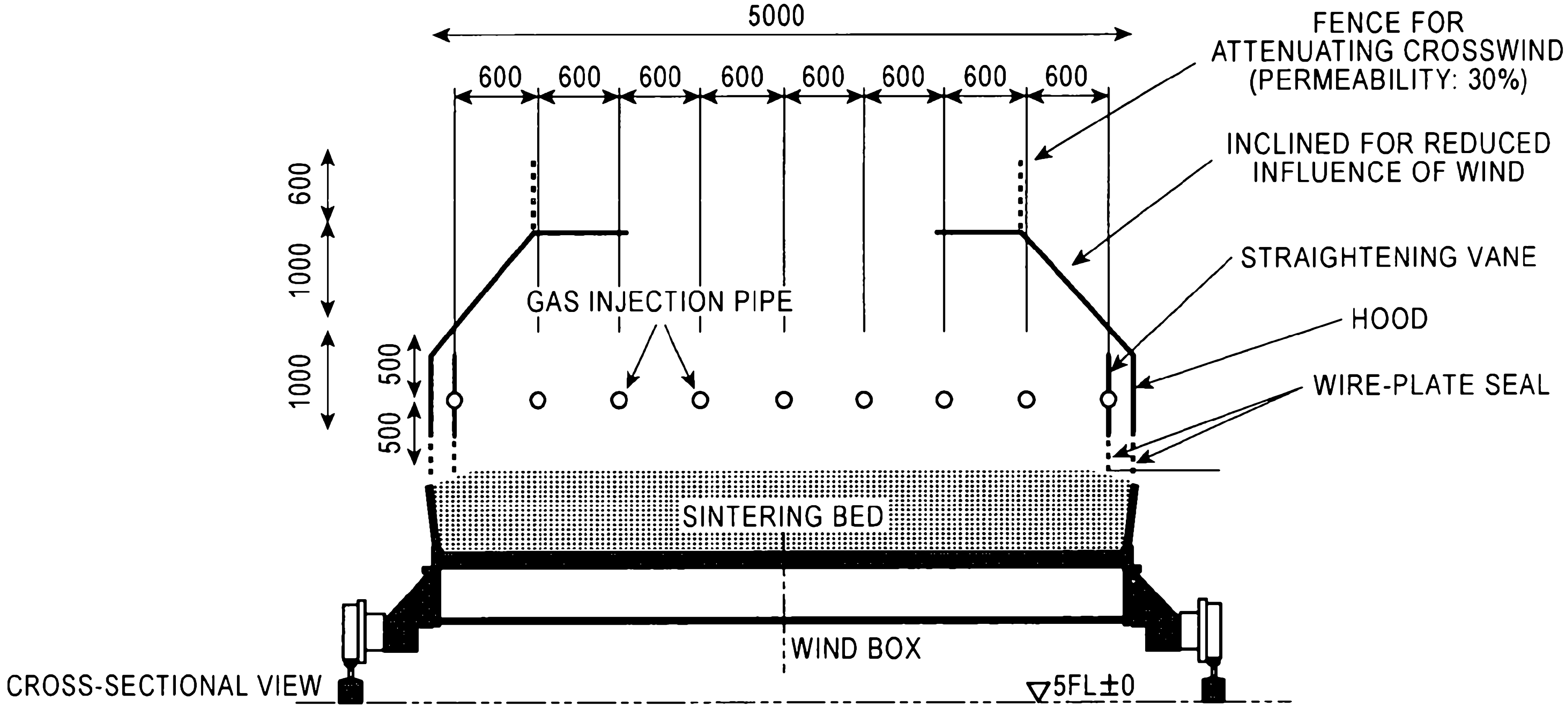

5000
600
600
600
600
600
600
600
600
FENCE FOR ATTENUATING CROSSWIND (PERMEABILITY: 30%)
INCLINED FOR REDUCED INFLUENCE OF WIND
STRAIGHTENING VANE
HOOD
WIRE-PLATE SEAL
600
1000
1000
500
500
GAS INJECTION PIPE
SINTERING BED
WIND BOX
CROSS-SECTIONAL VIEW
▽5FL±0

FIG. 23

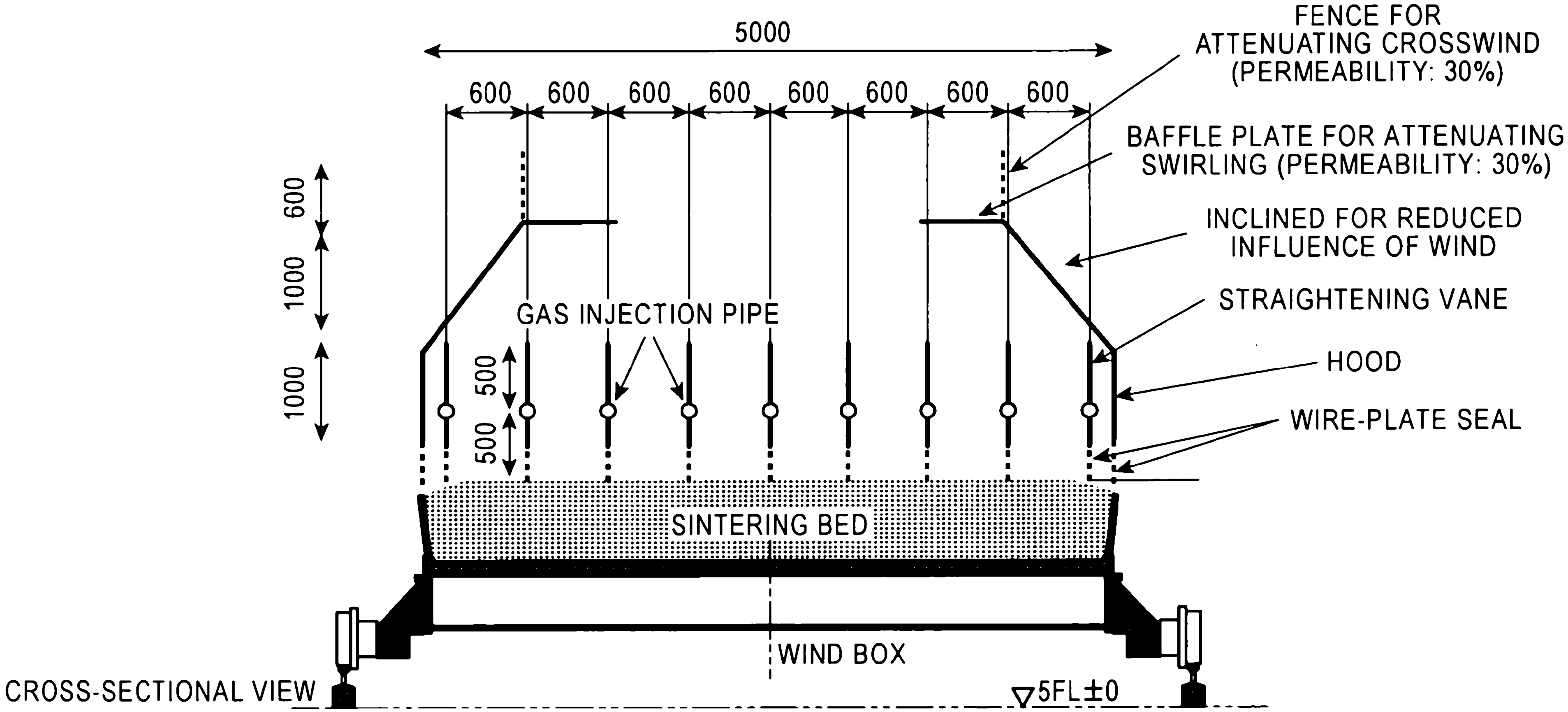

5000
600
600
600
600
600
600
600
600
FENCE FOR ATTENUATING CROSSWIND (PERMEABILITY: 30%)
BAFFLE PLATE FOR ATTENUATING SWIRLING (PERMEABILITY: 30%)
INCLINED FOR REDUCED INFLUENCE OF WIND
STRAIGHTENING VANE
HOOD
WIRE-PLATE SEAL
600
1000
1000
GAS INJECTION PIPE
500
500
SINTERING BED
WIND BOX
CROSS-SECTIONAL VIEW
▽5FL±0

FIG. 24

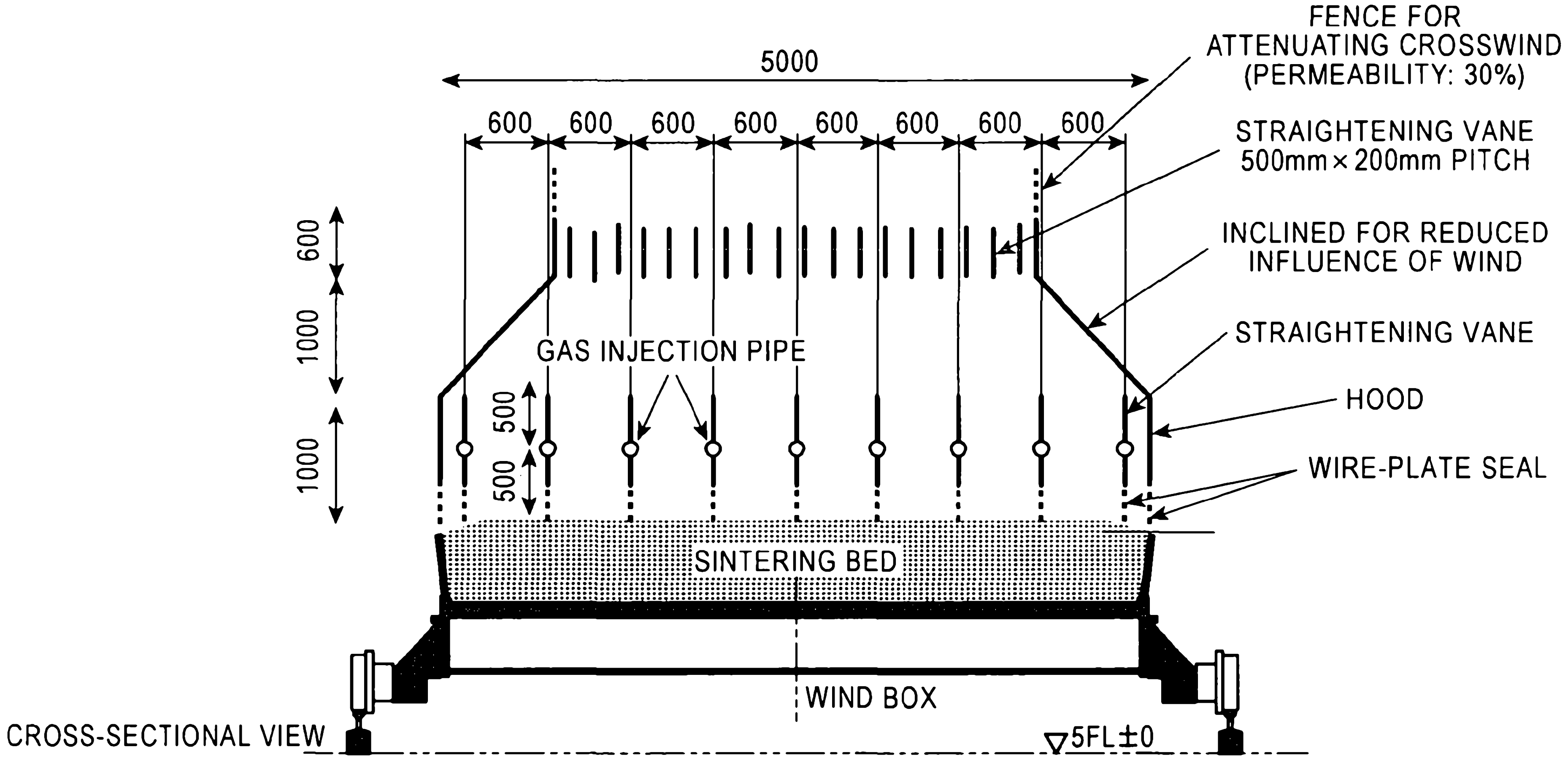

5000
600
600
600
600
600
600
600
600
FENCE FOR ATTENUATING CROSSWIND (PERMEABILITY: 30%)
STRAIGHTENING VANE 500mm × 200mm PITCH
INCLINED FOR REDUCED INFLUENCE OF WIND
STRAIGHTENING VANE
HOOD
WIRE-PLATE SEAL
600
1000
1000
GAS INJECTION PIPE
500
500
SINTERING BED
WIND BOX
CROSS-SECTIONAL VIEW
▽5FL±0

FIG. 25

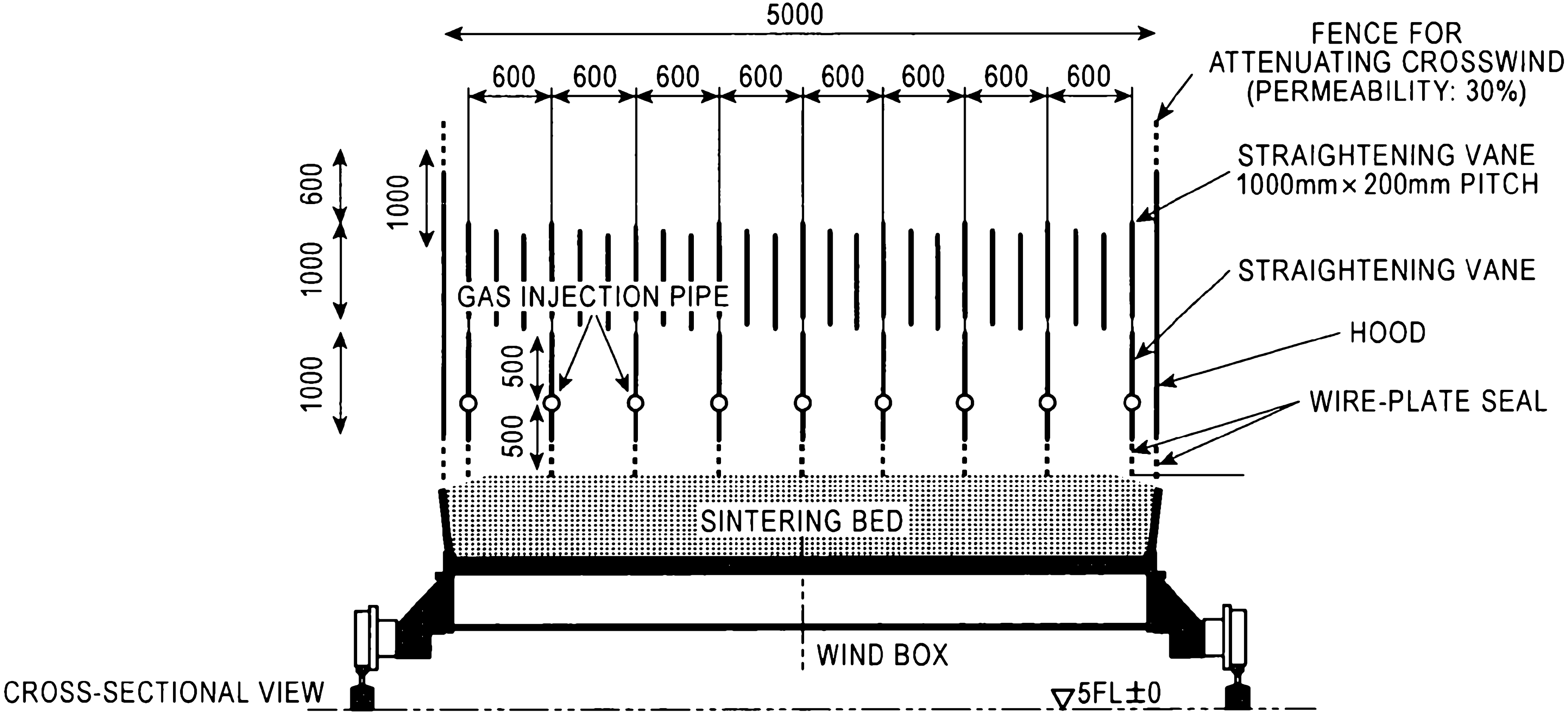

5000
600
600
600
600
600
600
600
600
FENCE FOR ATTENUATING CROSSWIND (PERMEABILITY: 30%)
STRAIGHTENING VANE 1000mm× 200mm PITCH
STRAIGHTENING VANE
HOOD
WIRE-PLATE SEAL
600
1000
1000
1000
GAS INJECTION PIPE
500
500
SINTERING BED
WIND BOX
CROSS-SECTIONAL VIEW
∇5FL±0

FIG. 26

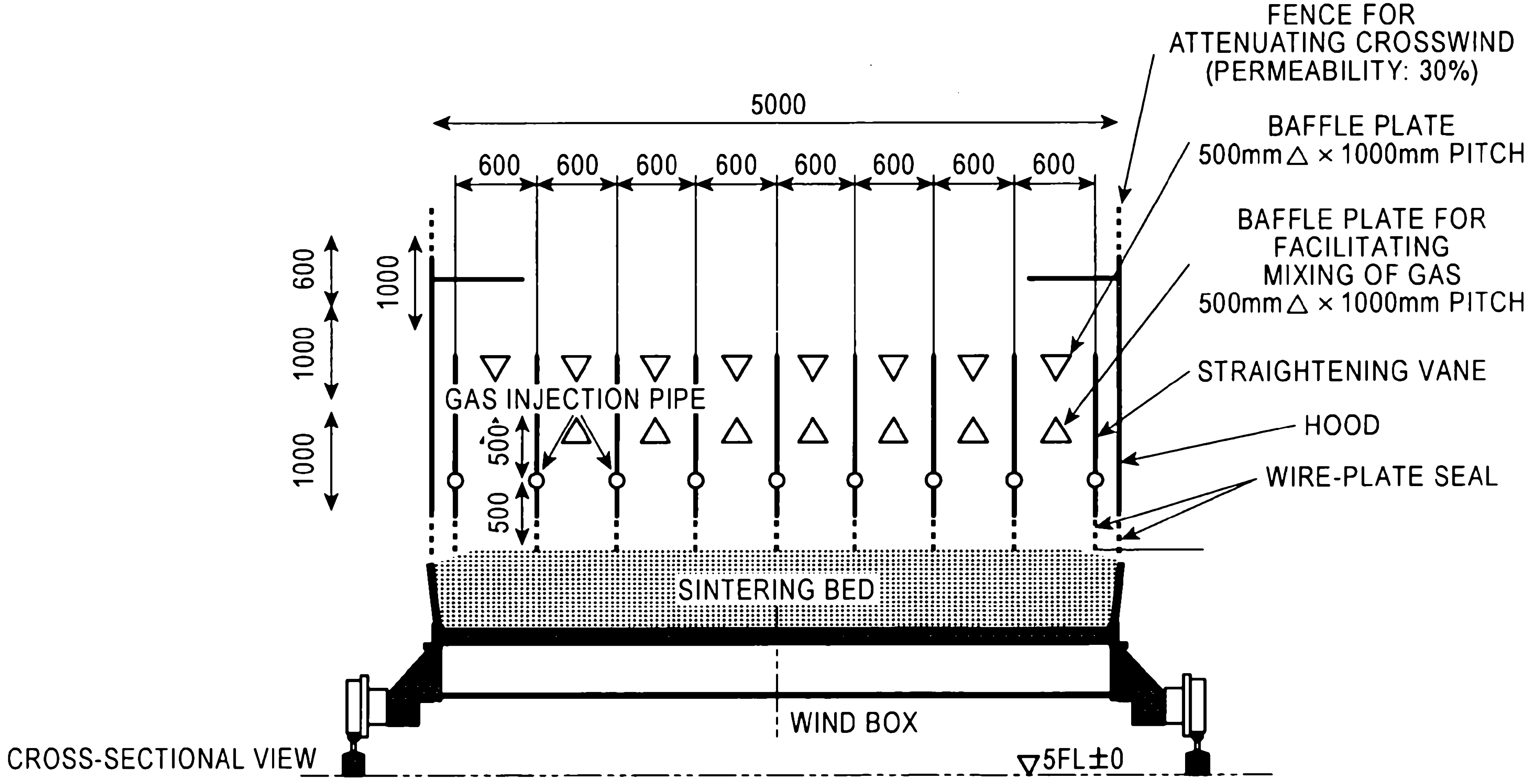

FENCE FOR
ATTENUATING CROSSWIND
(PERMEABILITY: 30%)
BAFFLE PLATE
500mm△ × 1000mm PITCH
BAFFLE PLATE FOR
FACILITATING
MIXING OF GAS
500mm△ × 1000mm PITCH
STRAIGHTENING VANE
HOOD
WIRE-PLATE SEAL
5000
600
600
600
600
600
600
600
600
1000
600
1000
1000
GAS INJECTION PIPE
500
500
SINTERING BED
WIND BOX
CROSS-SECTIONAL VIEW
▽5FL±0

FIG. 27

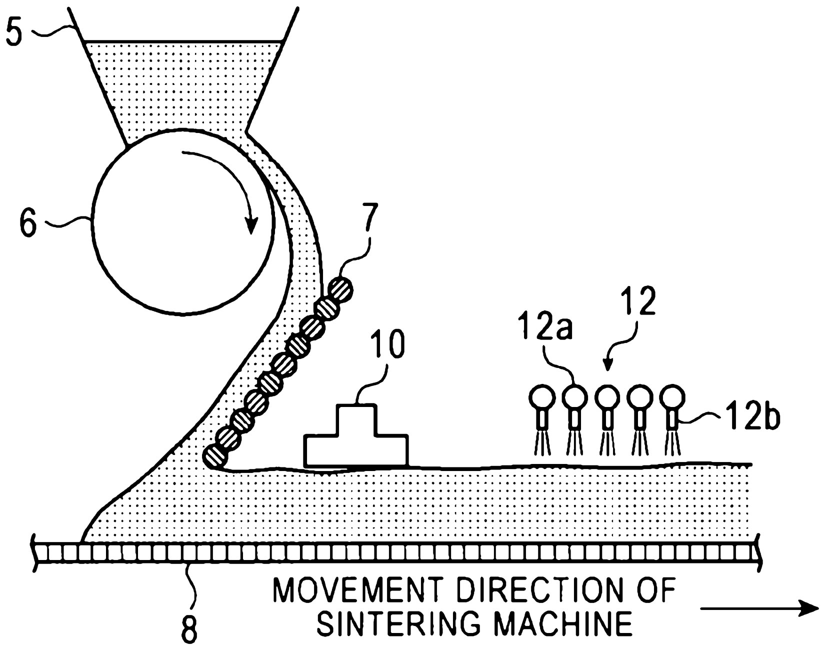


FIG. 28

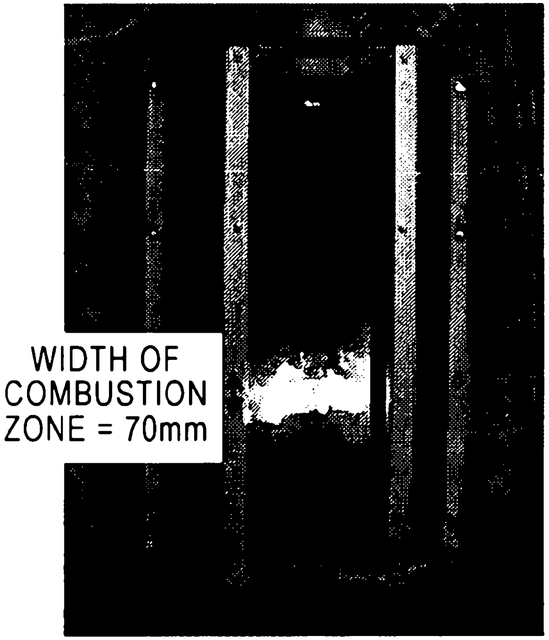
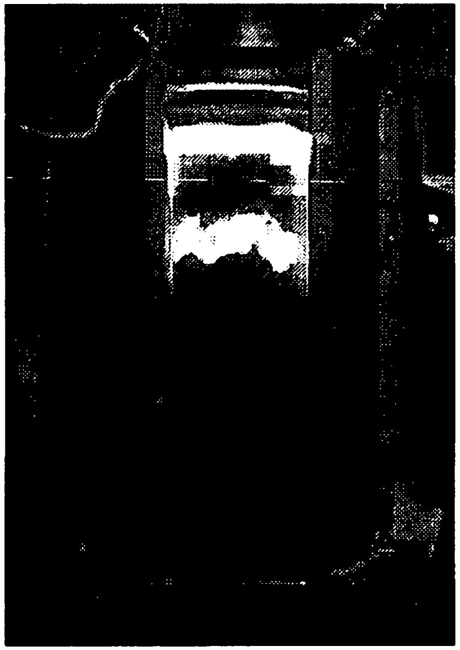
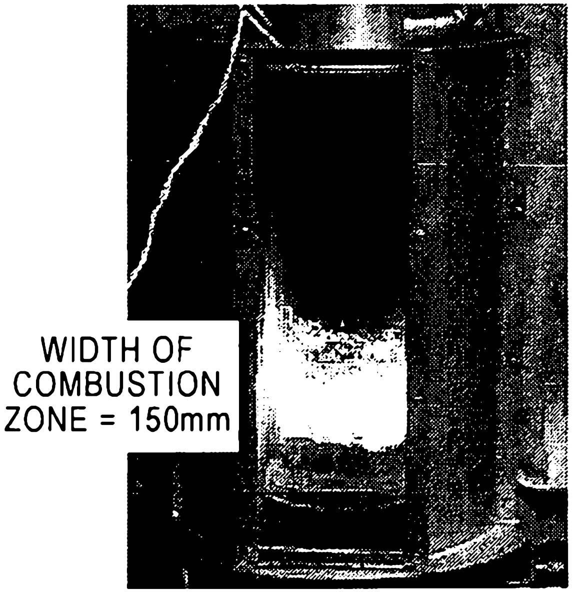
(1) AIR SINTERING	(2) INJECTION OF M-GAS (15 VOL%)	(3) INJECTION OF M-GAS (3 VOL%)
		
	M-GAS BURNED AT SURFACE IMMEDIATELY AFTER INJECTION	WIDTH OF COMBUSTION ZONE INCREASED

FIG. 29

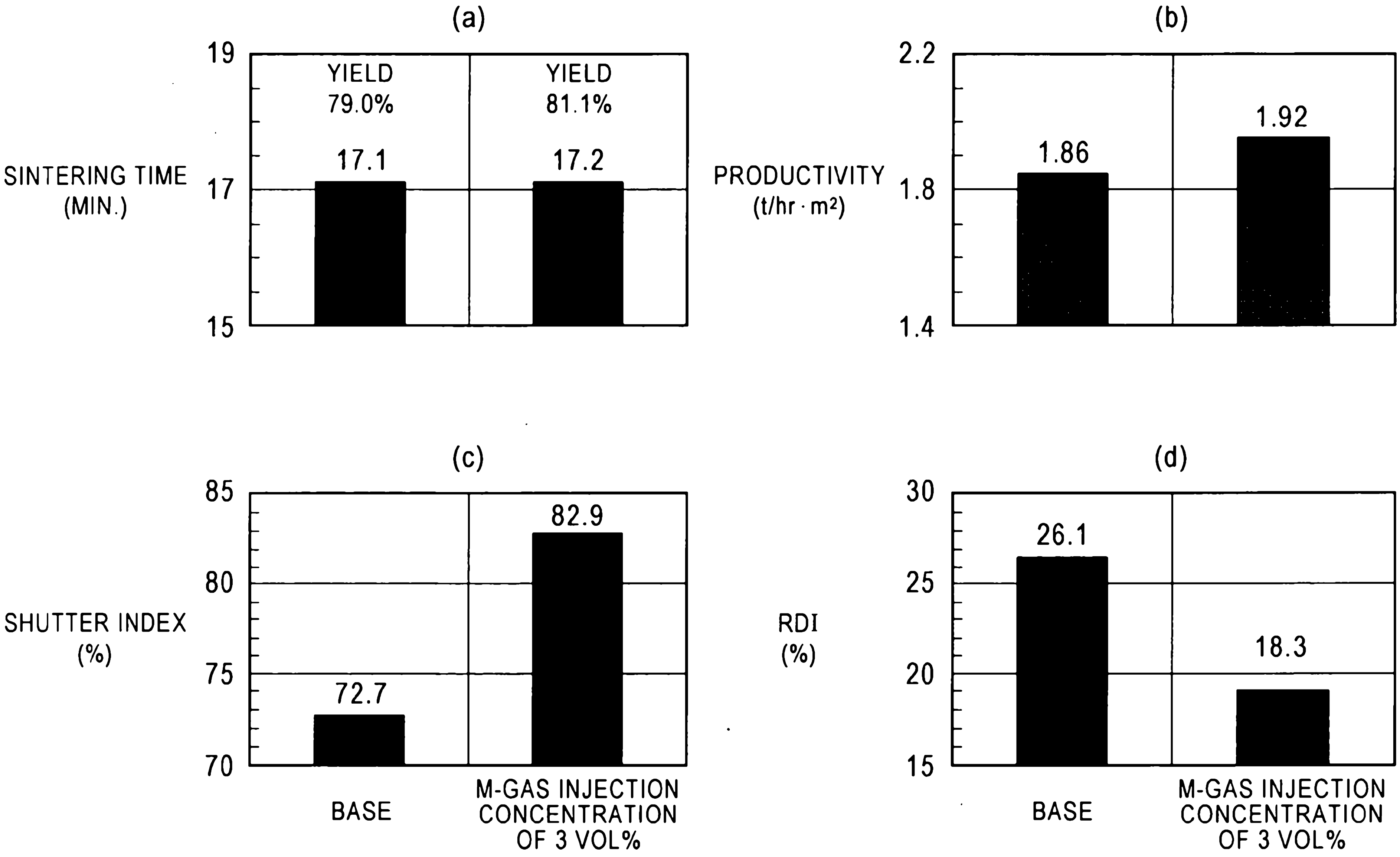
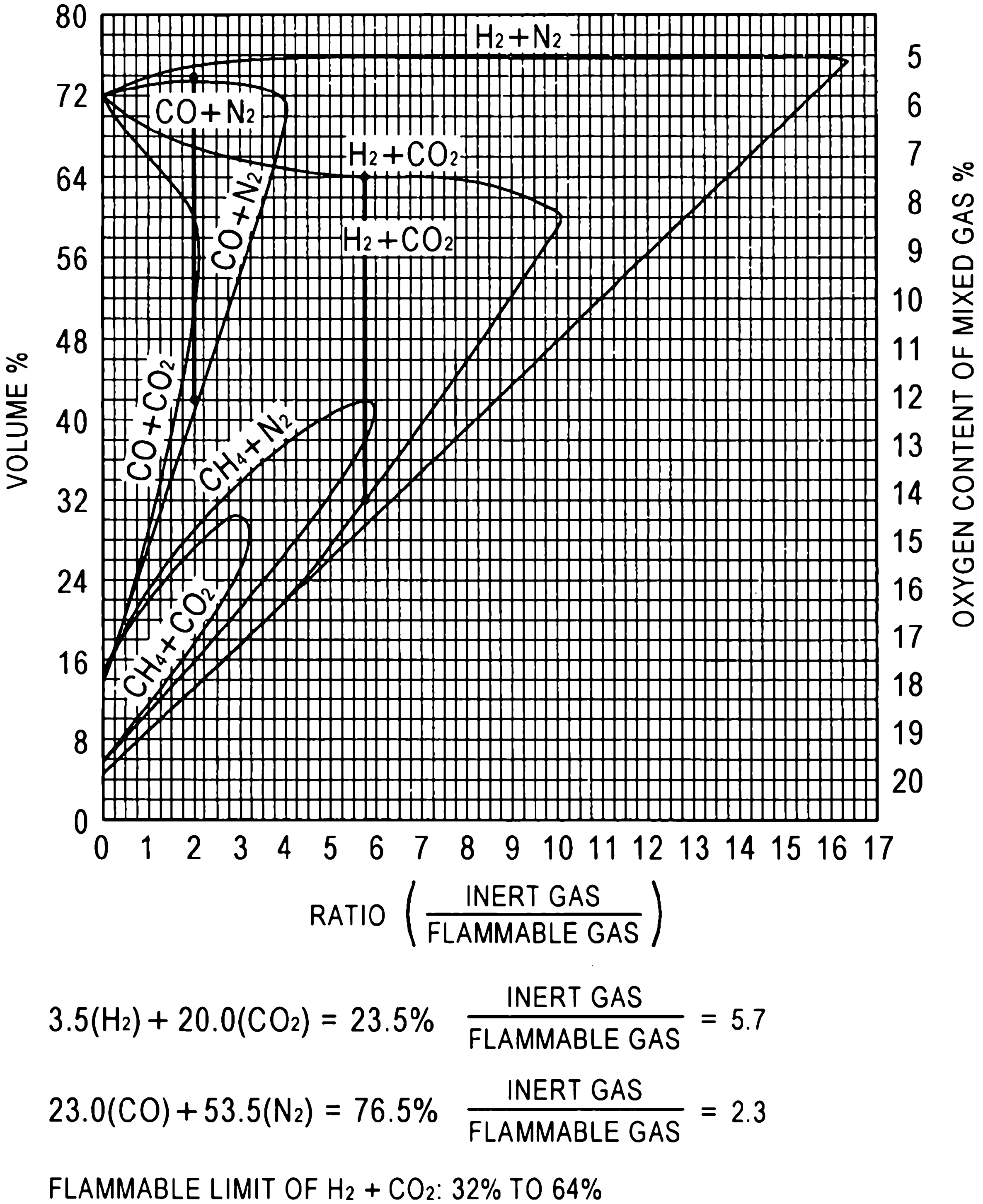

(a)
SINTERING TIME (MIN.)
19
17
15
YIELD 79.0%
17.1
YIELD 81.1%
17.2
(b)
PRODUCTIVITY (t/hr · m²)
2.2
1.8
1.4
1.86
1.92
(c)
SHUTTER INDEX (%)
85
80
75
70
72.7
82.9
BASE
M-GAS INJECTION CONCENTRATION OF 3 VOL%
(d)
RDI (%)
30
25
20
15
26.1
18.3
BASE
M-GAS INJECTION CONCENTRATION OF 3 VOL%

FIG. 30



$3.5(H_2)+20.0(CO_2) = 23.5\% \quad \frac{\text{INERT GAS}}{\text{FLAMMABLE GAS}} = 5.7$

$23.0(CO)+53.5(N_2) = 76.5\% \quad \frac{\text{INERT GAS}}{\text{FLAMMABLE GAS}} = 2.3$

FLAMMABLE LIMIT OF $H_2 + CO_2$: 32% TO 64%

FLAMMABLE LIMIT OF $CO + N_2$: 44% TO 74%

$$\text{LOWER FLAMMABLE LIMIT} = \frac{100}{23.5/32 + 76.5/44} \approx 40\%$$

FIG. 31

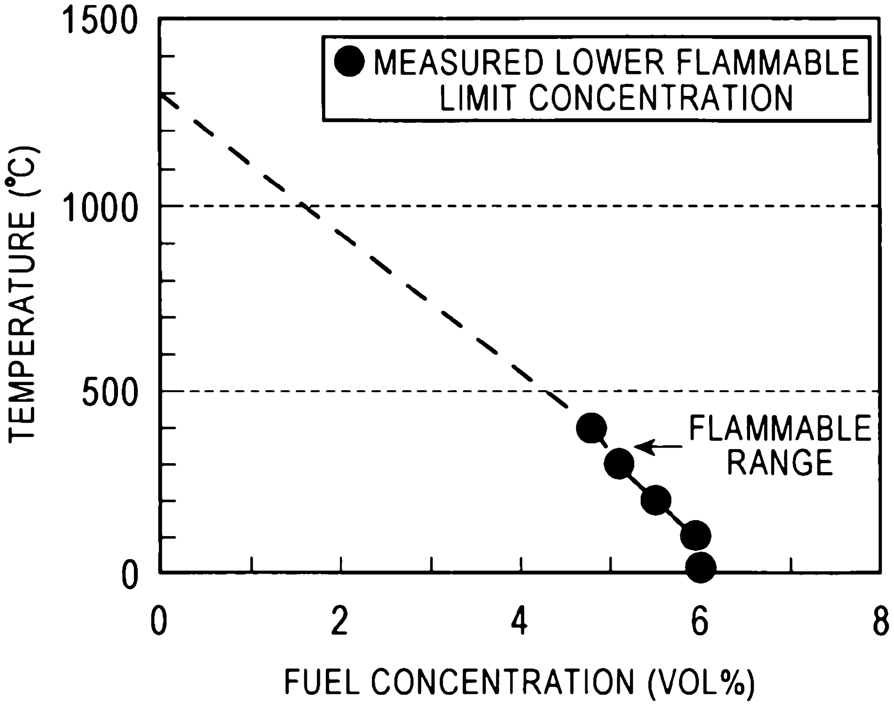

● MEASURED LOWER FLAMMABLE LIMIT CONCENTRATION
FLAMMABLE RANGE
TEMPERATURE (°C)
1500
1000
500
0
0
2
4
6
8
FUEL CONCENTRATION (VOL%)

FIG. 32

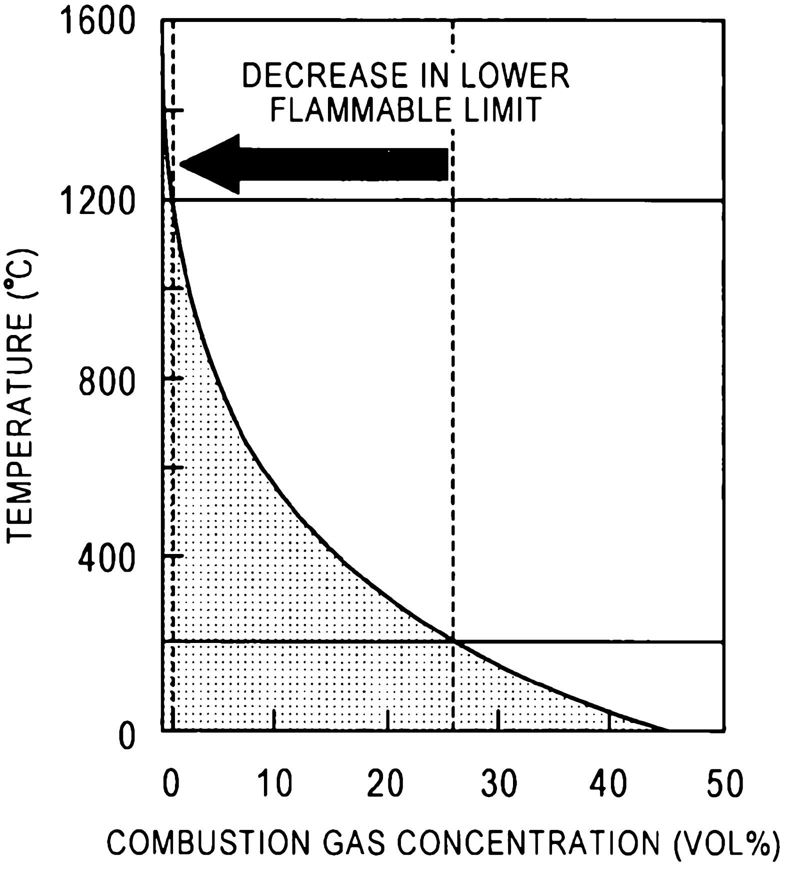

DECREASE IN LOWER FLAMMABLE LIMIT
TEMPERATURE (°C)
1600
1200
800
400
0
0
10
20
30
40
50
COMBUSTION GAS CONCENTRATION (VOL%)

FIG. 33

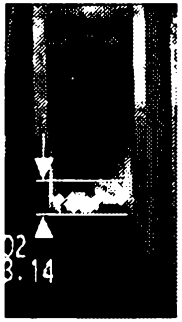
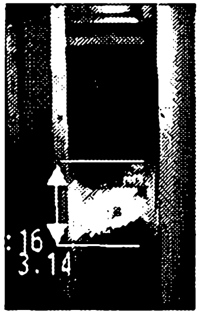
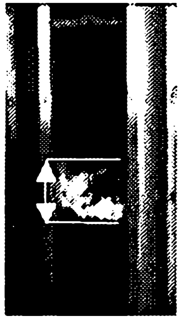
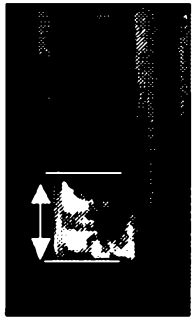
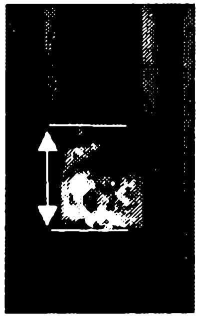
INJECTION GAS SPECIES	CONVENTIONAL SINTERING	PROPANE GAS	H_2 GAS	CO GAS	METHANE GAS	C-GAS	LNG
CONCENTRATION (VOL% TO AIR)	–	0.4	3.0	2.4	0.9	2.0	0.8
COKE FINES (MASS%)	5.0	4.2	4.2	4.2	4.2	4.2	4.2
MOLECULAR WEIGHT	–	44	2	28	16	8.6	18.4
AVERAGE IGNITION TEMPERATURE (℃)	–	568	585	666	700	ABOUT 630	ABOUT 670
SHUTTER INDEX (%)	67.7	75.5	76.0	74.1	74.5	75.4	75.5
PRODUCT YIELD (%)	69.0	72.8	74.6	73.4	73.9	74.6	75.9
SINTERING TIME (MIN.)	16.0	16.7	17.1	18.6	18.8	17.3	18.3
PRODUCTIVITY ($t/hr \cdot m^2$)	1.56	1.64	1.63	1.58	1.55	1.64	1.65
COMBUSTION CONDITION							

FIG. 34

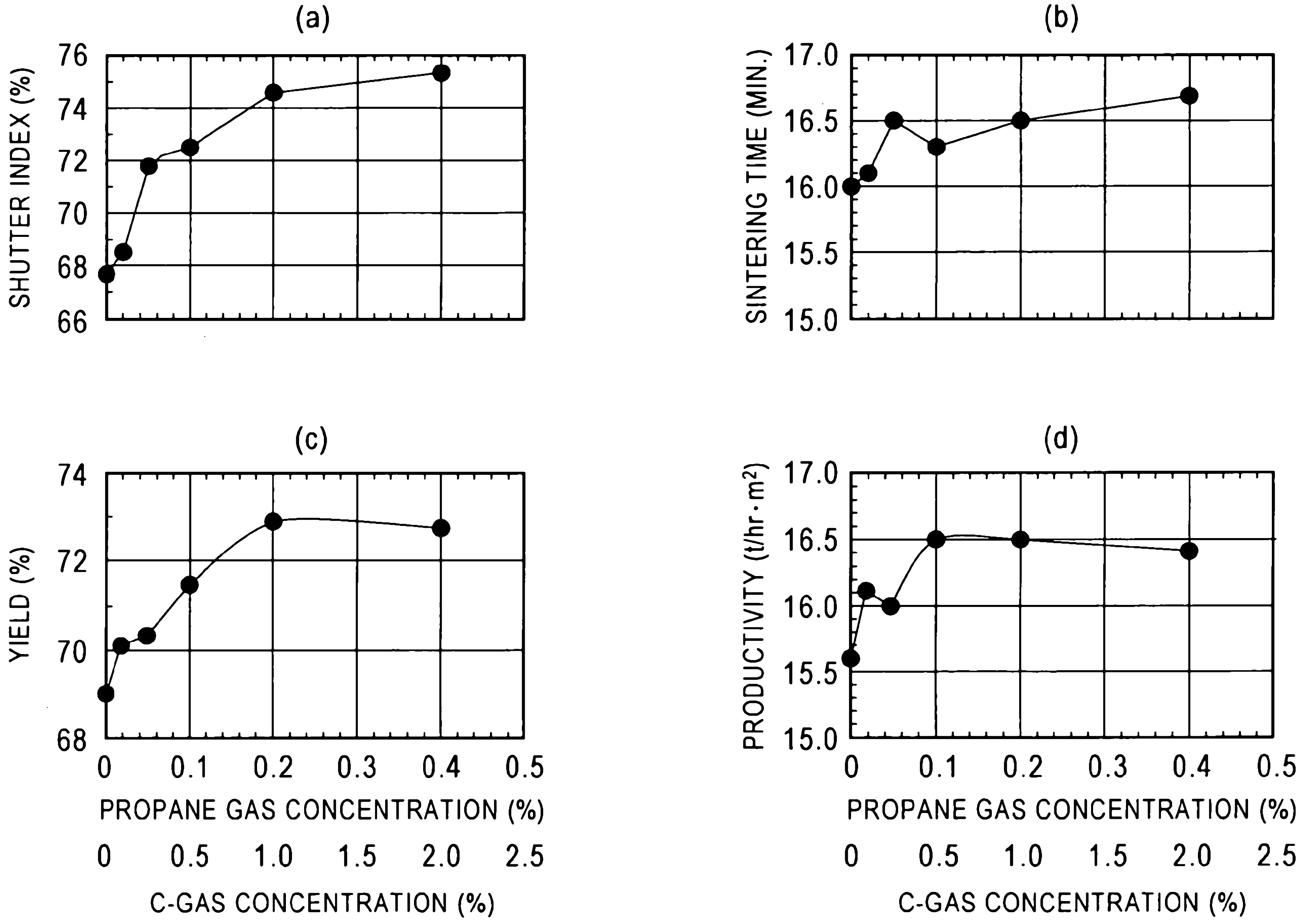

(a)
SHUTTER INDEX (%)
76
74
72
70
68
66
(b)
SINTERING TIME (MIN.)
17.0
16.5
16.0
15.5
15.0
(c)
YIELD (%)
74
72
70
68
0
0.1
0.2
0.3
0.4
0.5
PROPANE GAS CONCENTRATION (%)
0
0.5
1.0
1.5
2.0
2.5
C-GAS CONCENTRATION (%)
(d)
PRODUCTIVITY (t/hr·m²)
17.0
16.5
16.0
15.5
15.0
0
0.1
0.2
0.3
0.4
0.5
PROPANE GAS CONCENTRATION (%)
0
0.5
1.0
1.5
2.0
2.5
C-GAS CONCENTRATION (%)

FIG. 35

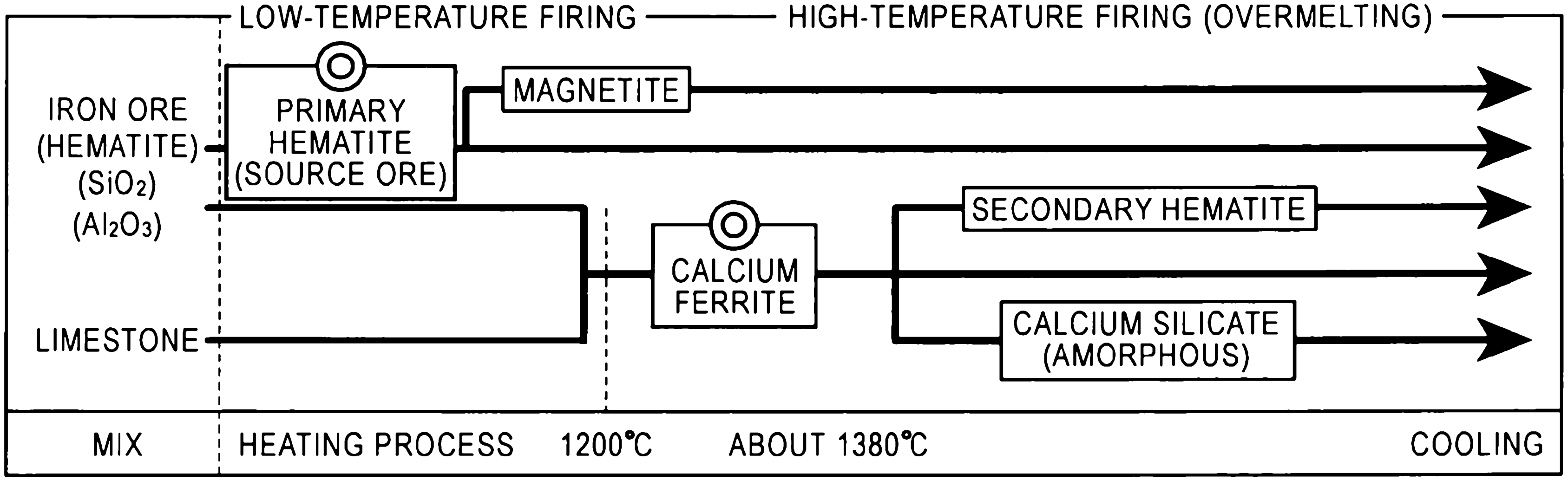

LOW-TEMPERATURE FIRING
HIGH-TEMPERATURE FIRING (OVERMELTING)
IRON ORE
(HEMATITE)
(SiO_2)
(Al_2O_3)
LIMESTONE
PRIMARY
HEMATITE
(SOURCE ORE)
MAGNETITE
CALCIUM
FERRITE
SECONDARY HEMATITE
CALCIUM SILICATE
(AMORPHOUS)
MIX
HEATING PROCESS
1200℃
ABOUT 1380℃
COOLING

FIG. 36

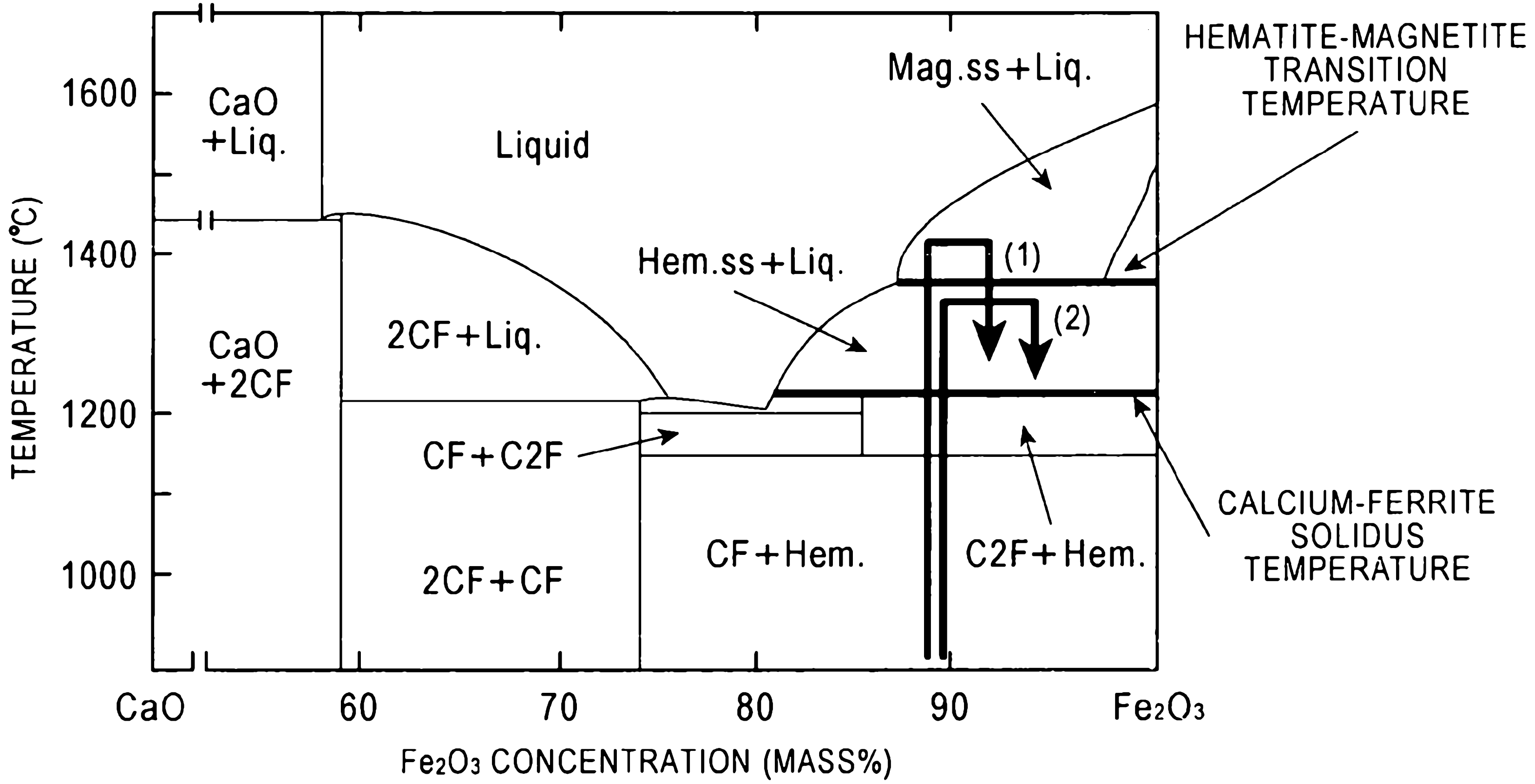

TEMPERATURE (°C)
1600
1400
1200
1000
CaO
60
70
80
90
Fe2O3
Fe2O3 CONCENTRATION (MASS%)
CaO +Liq.
CaO +2CF
Liquid
2CF+Liq.
CF+C2F
2CF+CF
Hem.ss+Liq.
CF+Hem.
Mag.ss+Liq.
C2F+Hem.
(1)
(2)
HEMATITE-MAGNETITE TRANSITION TEMPERATURE
CALCIUM-FERRITE SOLIDUS TEMPERATURE

FIG. 37

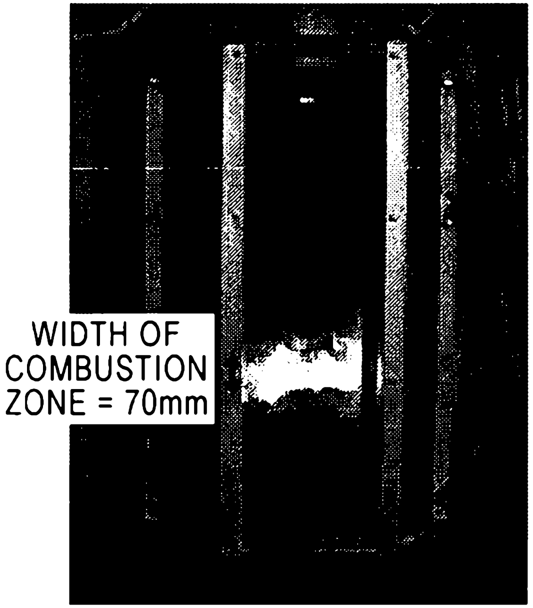
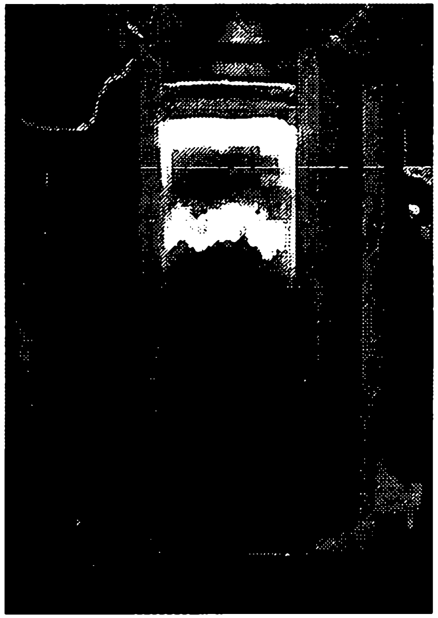
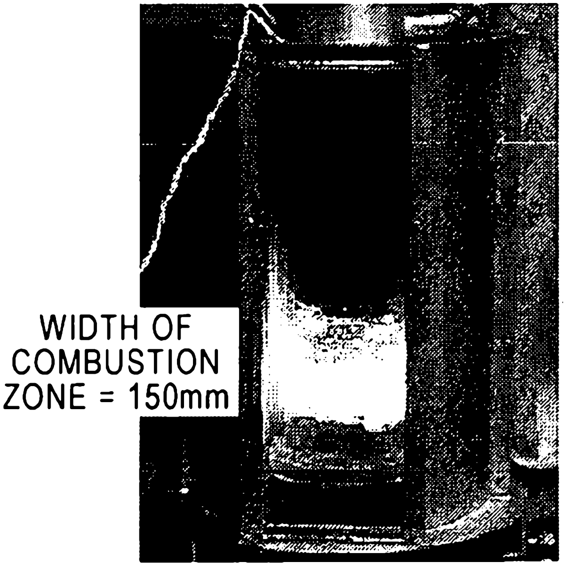
(1) COKE FINES ONLY	(2) INJECTION OF PROPANE GAS (CONCENTRATION: 2.5 VOL%)	(3) INJECTION OF PROPANE GAS (CONCENTRATION: 0.5 VOL%)
		
NARROW COMBUSTION AND MELTING ZONE	PROPANE GAS BURNED AT SURFACE IMMEDIATELY AFTER INJECTION	WIDTH OF COMBUSTION AND MELTING ZONE INCREASED

FIG. 38

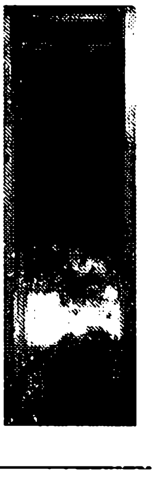
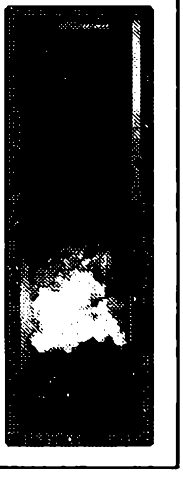
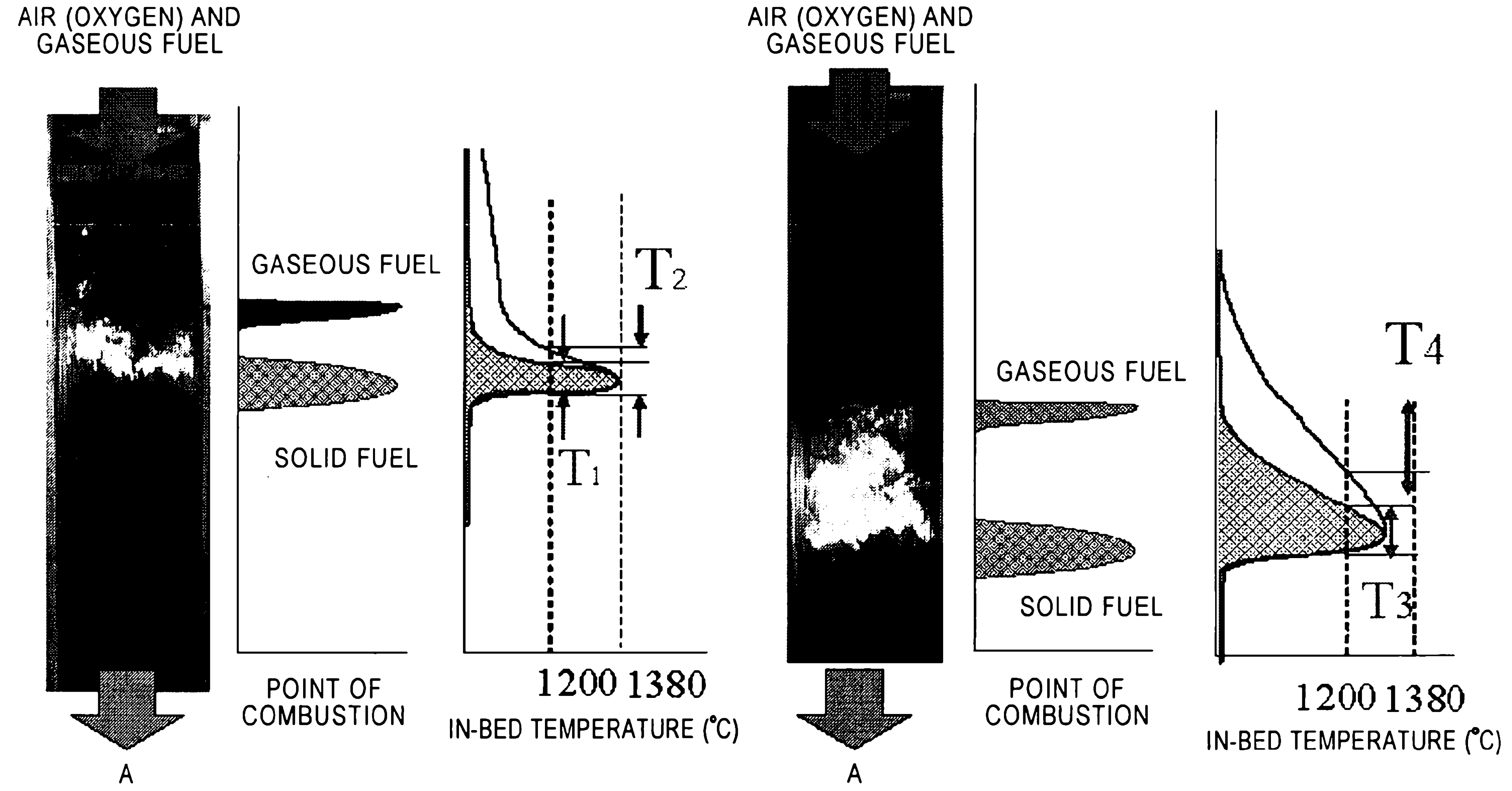
INJECTION POSITION (mm)	(CONVENTIONAL METHOD) NONE	100 TO 200	200 TO 300	300 TO 400
SECOND OF FOUR SEGMENTS FROM SURFACE (100 TO 200 mm)				
THIRD OF FOUR SEGMENTS FROM SURFACE (200 TO 300 mm)				
FOURTH OF FOUR SEGMENTS FROM SURFACE (300 TO 400 mm)				

FIG. 39

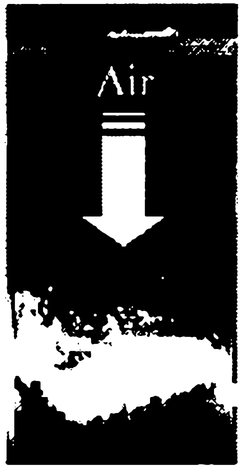
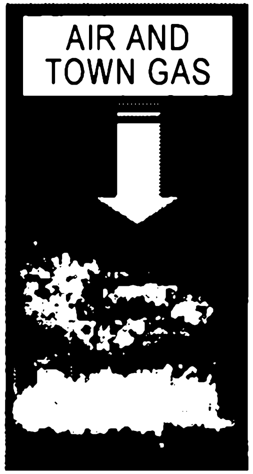
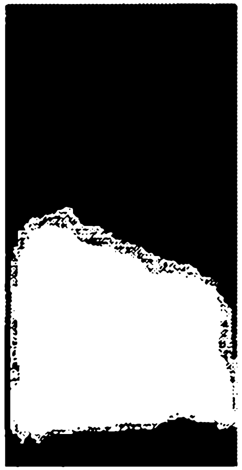

(a)

(INJECTION INTO UPPER LAYER)

(b)

(INJECTION INTO MIDDLE AND LOWER LAYERS)

FIG. 40

	CONVENTIONAL SINTERING : COKE FINES ONLY		FIRING WITH TOWN GAS	
TOWN GAS CONCENTRATION (VOL.%)	—		0.4	
COKE FINE PROPORTION (%)	4.2		3.6	
COMBUSTION CONDITION	VIDEO	THERMO VIEWER	VIDEO	THERMO VIEWER
				

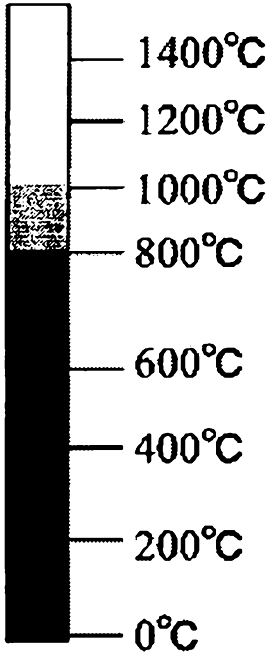


FIG. 41

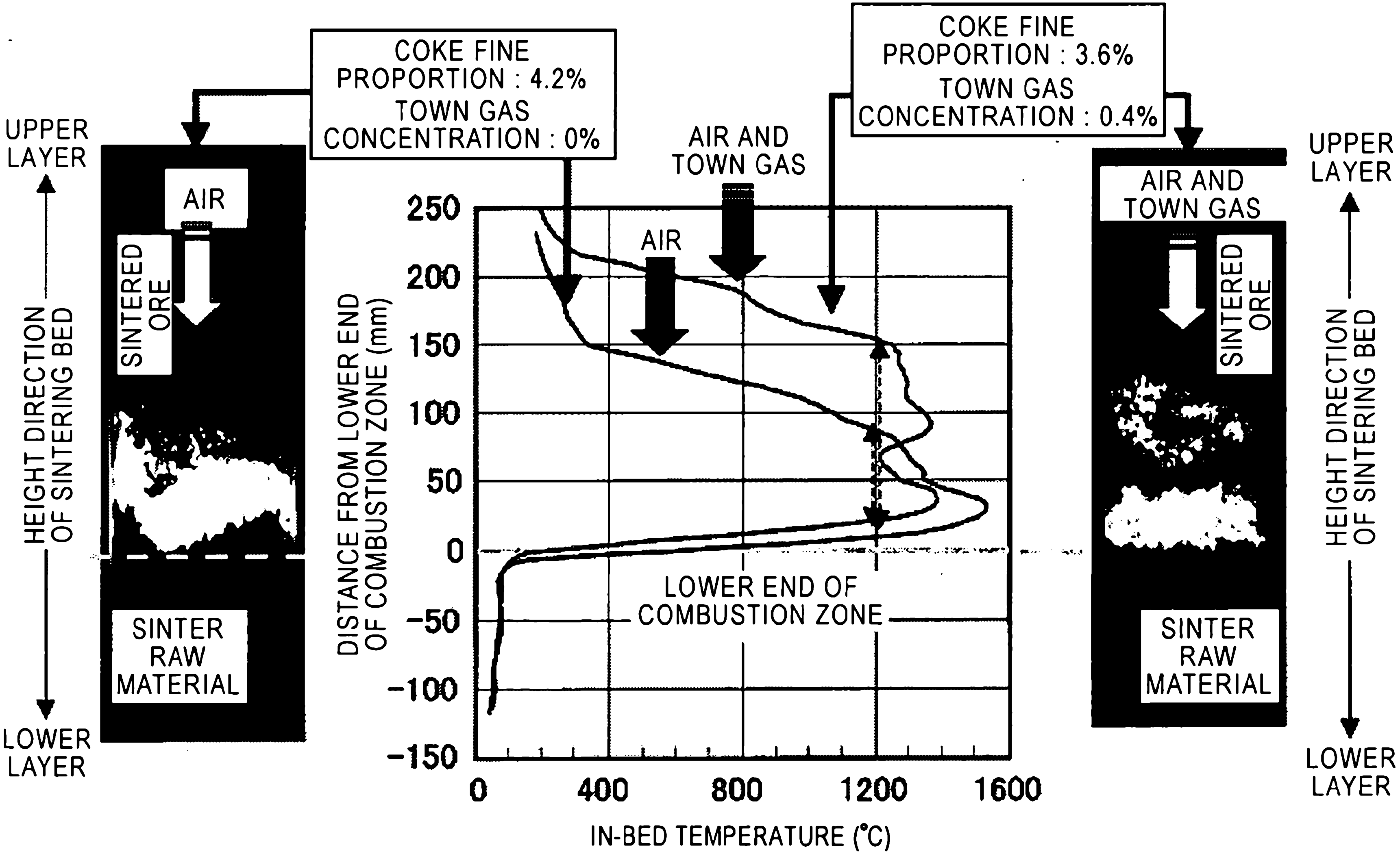
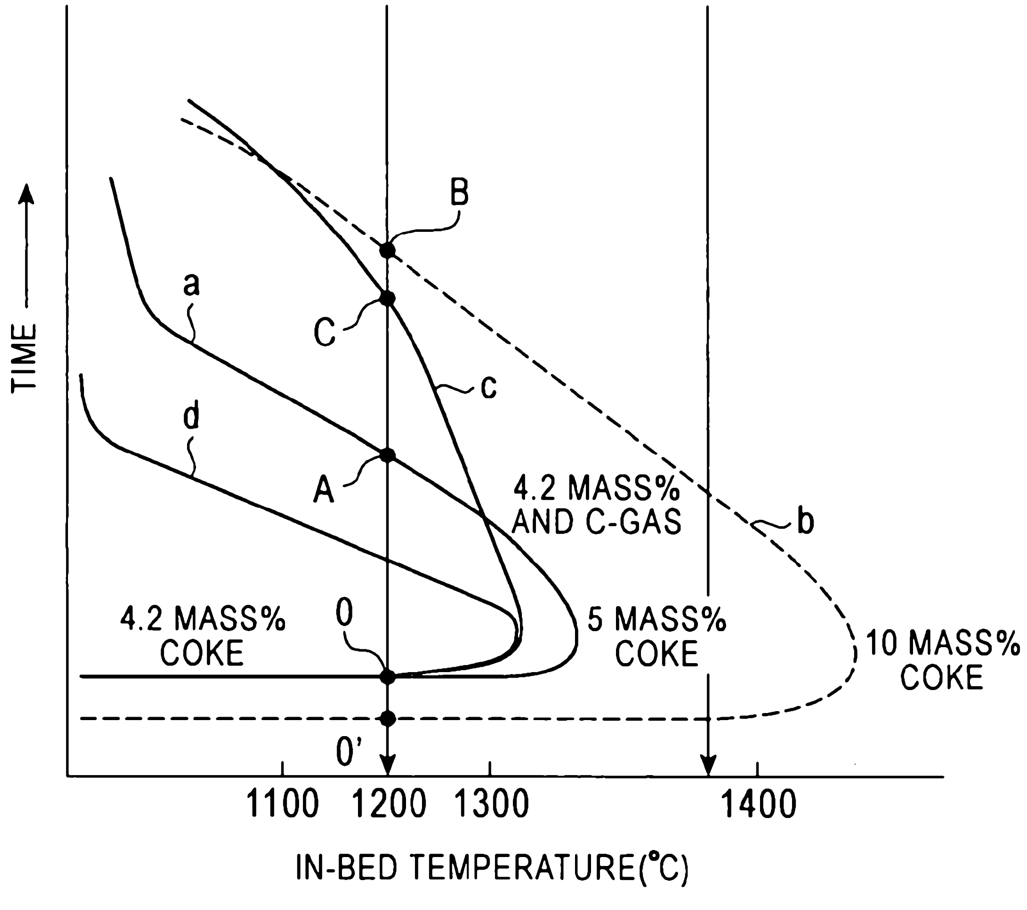
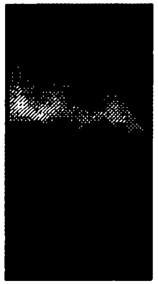
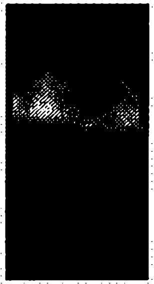
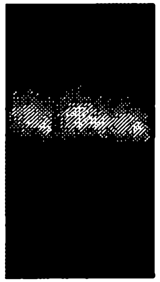

COKE FINE
PROPORTION : 4.2%
TOWN GAS
CONCENTRATION : 0%
COKE FINE
PROPORTION : 3.6%
TOWN GAS
CONCENTRATION : 0.4%
UPPER LAYER
LOWER LAYER
HEIGHT DIRECTION OF SINTERING BED
AIR
SINTERED ORE
SINTER RAW MATERIAL
AIR AND TOWN GAS
AIR
AIR AND TOWN GAS
250
200
150
100
50
0
−50
−100
−150
DISTANCE FROM LOWER END OF COMBUSTION ZONE (mm)
0
400
800
1200
1600
IN-BED TEMPERATURE (°C)
LOWER END OF COMBUSTION ZONE
AIR AND TOWN GAS
SINTERED ORE
SINTER RAW MATERIAL
UPPER LAYER
LOWER LAYER
HEIGHT DIRECTION OF SINTERING BED

FIG. 42



TIME
B
C
a
c
d
A
4.2 MASS%
AND C-GAS
b
0
4.2 MASS%
COKE
5 MASS%
COKE
10 MASS%
COKE
0'
1100
1200
1300
1400
IN-BED TEMPERATURE(°C)

FIG. 43

	CONVENTIONAL SINTERING METHOD		EXAMPLE ACCORDING TO INVENTION			
INJECTION GAS CONCENTRATION (VOL%)	NONE		C-GAS : 2.0			
AMOUNT OF COKE USED (MASS%)	5.0		4.2			
INJECTION POSITION	—		INJECTION INTO ENTIRE BED (400 mm)		INJECTION INTO LOWER HALF (200 mm)	
DRYING METHOD	VIDEO	THERMOVIEWER	VIDEO	THERMOVIEWER	VIDEO	THERMOVIEWER
COMBUSTION CONDITION OF UPPER LAYER						
COMBUSTION CONDITION OF LOWER LAYER						

THERMOVIEWER SCALE :

FIG. 44

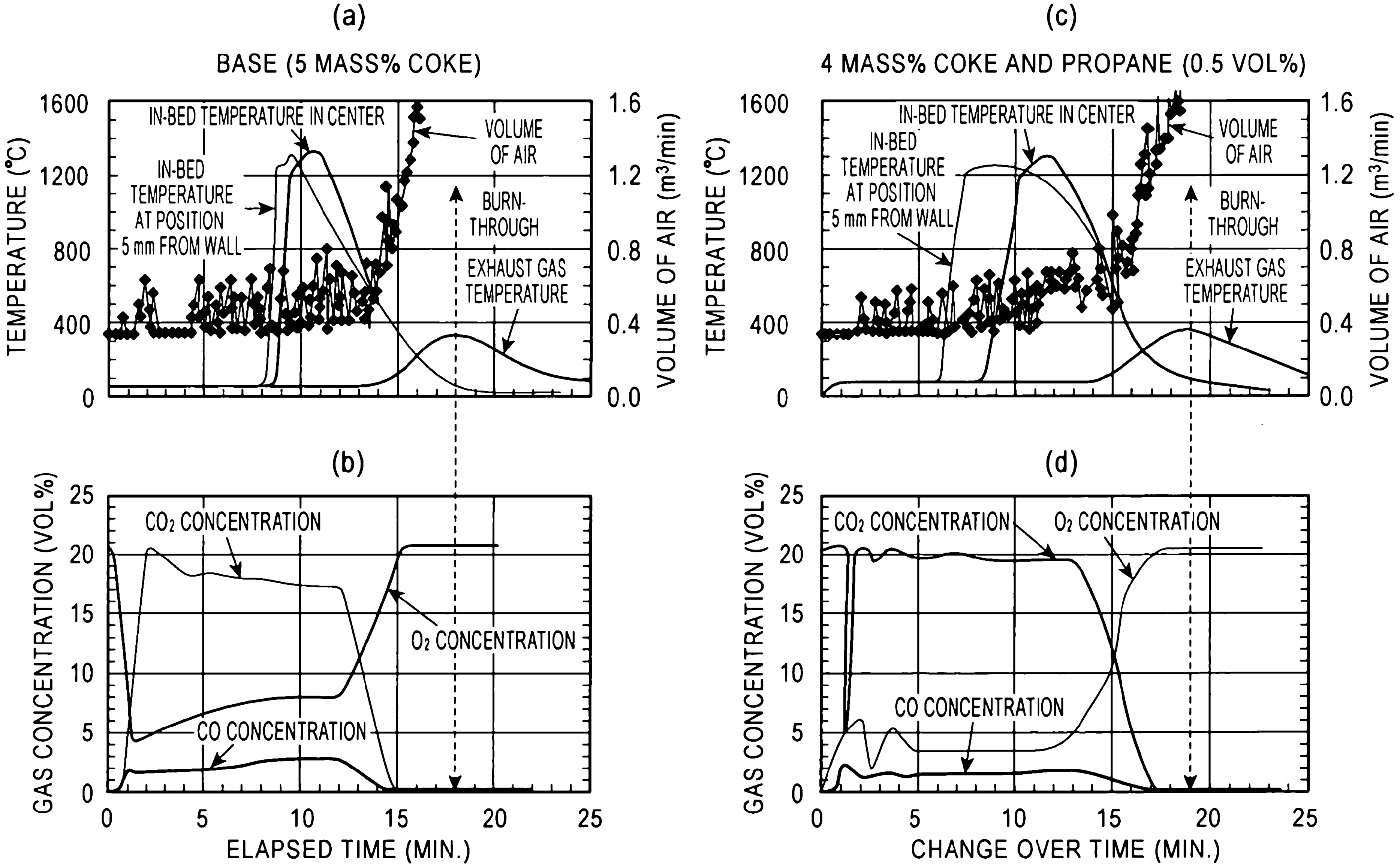
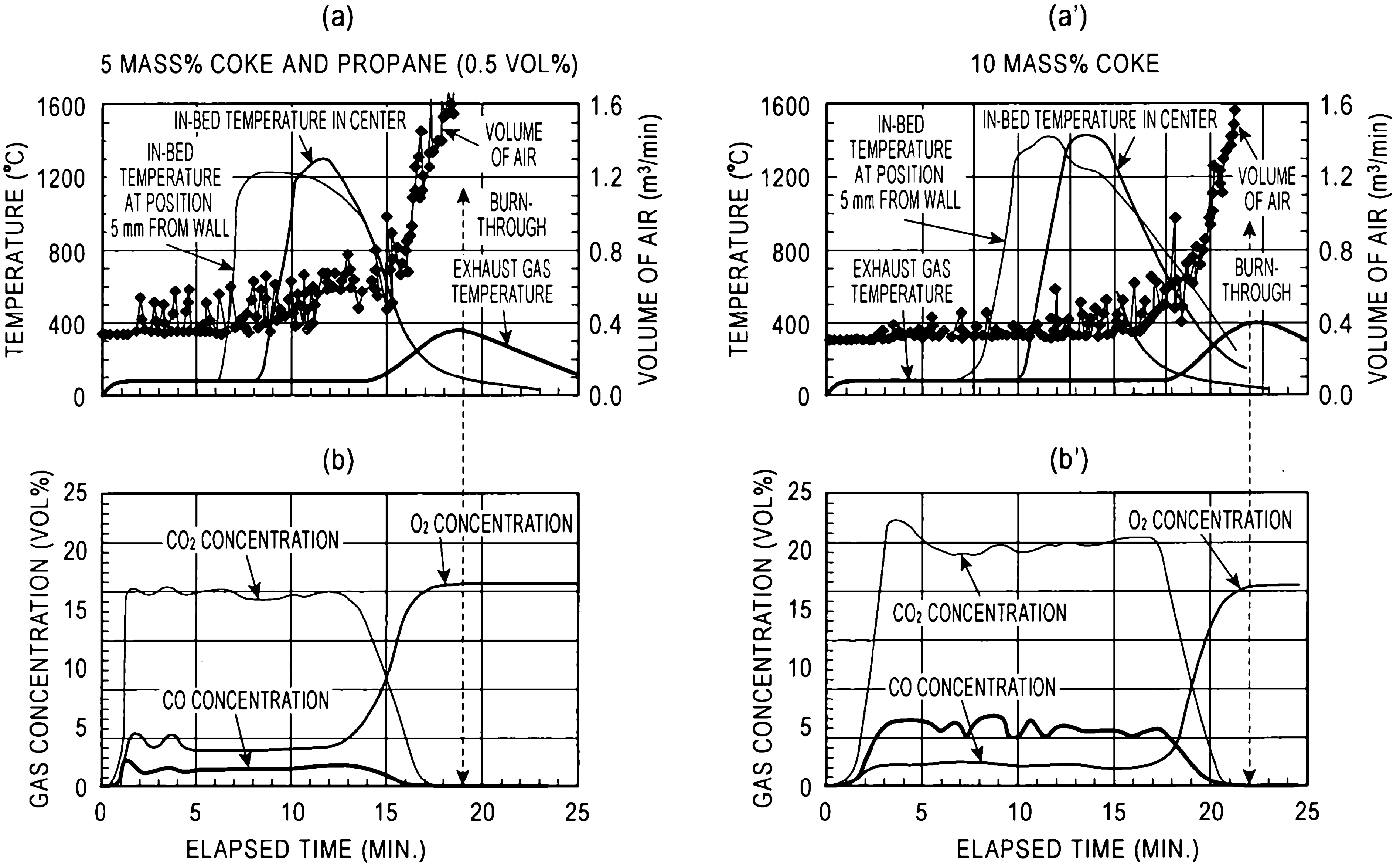

(a)
BASE (5 MASS% COKE)
TEMPERATURE (°C)
1600
1200
800
400
0
IN-BED TEMPERATURE IN CENTER
IN-BED TEMPERATURE AT POSITION 5 mm FROM WALL
VOLUME OF AIR
BURN-THROUGH
EXHAUST GAS TEMPERATURE
1.6
1.2
0.8
0.4
0.0
VOLUME OF AIR (m³/min)
(b)
GAS CONCENTRATION (VOL%)
25
20
15
10
5
0
CO2 CONCENTRATION
O2 CONCENTRATION
CO CONCENTRATION
0
5
10
15
20
25
ELAPSED TIME (MIN.)
(c)
4 MASS% COKE AND PROPANE (0.5 VOL%)
TEMPERATURE (°C)
1600
1200
800
400
0
IN-BED TEMPERATURE IN CENTER
IN-BED TEMPERATURE AT POSITION 5 mm FROM WALL
VOLUME OF AIR
BURN-THROUGH
EXHAUST GAS TEMPERATURE
1.6
1.2
0.8
0.4
0.0
VOLUME OF AIR (m³/min)
(d)
GAS CONCENTRATION (VOL%)
25
20
15
10
5
0
CO2 CONCENTRATION
O2 CONCENTRATION
CO CONCENTRATION
0
5
10
15
20
25
CHANGE OVER TIME (MIN.)

FIG. 45



(a)

5 MASS% COKE AND PROPANE (0.5 VOL%)

(a')

10 MASS% COKE

(b)

(b')

FIG. 46

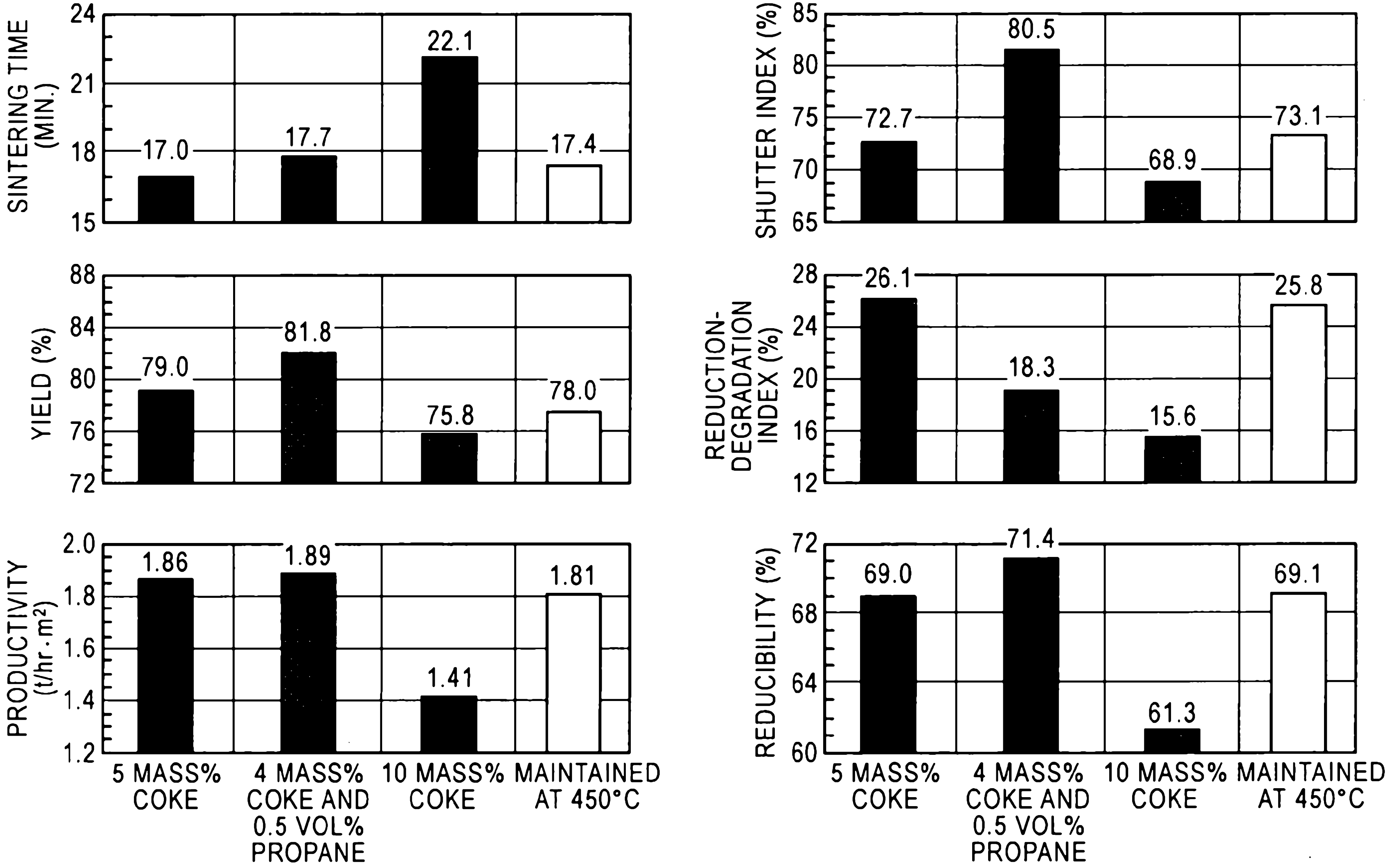

SINTERING TIME (MIN.)
24
21
18
15
17.0
17.7
22.1
17.4
YIELD (%)
88
84
80
76
72
79.0
81.8
75.8
78.0
PRODUCTIVITY (t/hr.m²)
2.0
1.8
1.6
1.4
1.2
1.86
1.89
1.41
1.81
5 MASS% COKE
4 MASS% COKE AND 0.5 VOL% PROPANE
10 MASS% COKE
MAINTAINED AT 450°C
SHUTTER INDEX (%)
85
80
75
70
65
72.7
80.5
68.9
73.1
REDUCTION-DEGRADATION INDEX (%)
28
24
20
16
12
26.1
18.3
15.6
25.8
REDUCIBILITY (%)
72
68
64
60
69.0
71.4
61.3
69.1
5 MASS% COKE
4 MASS% COKE AND 0.5 VOL% PROPANE
10 MASS% COKE
MAINTAINED AT 450°C

FIG. 47

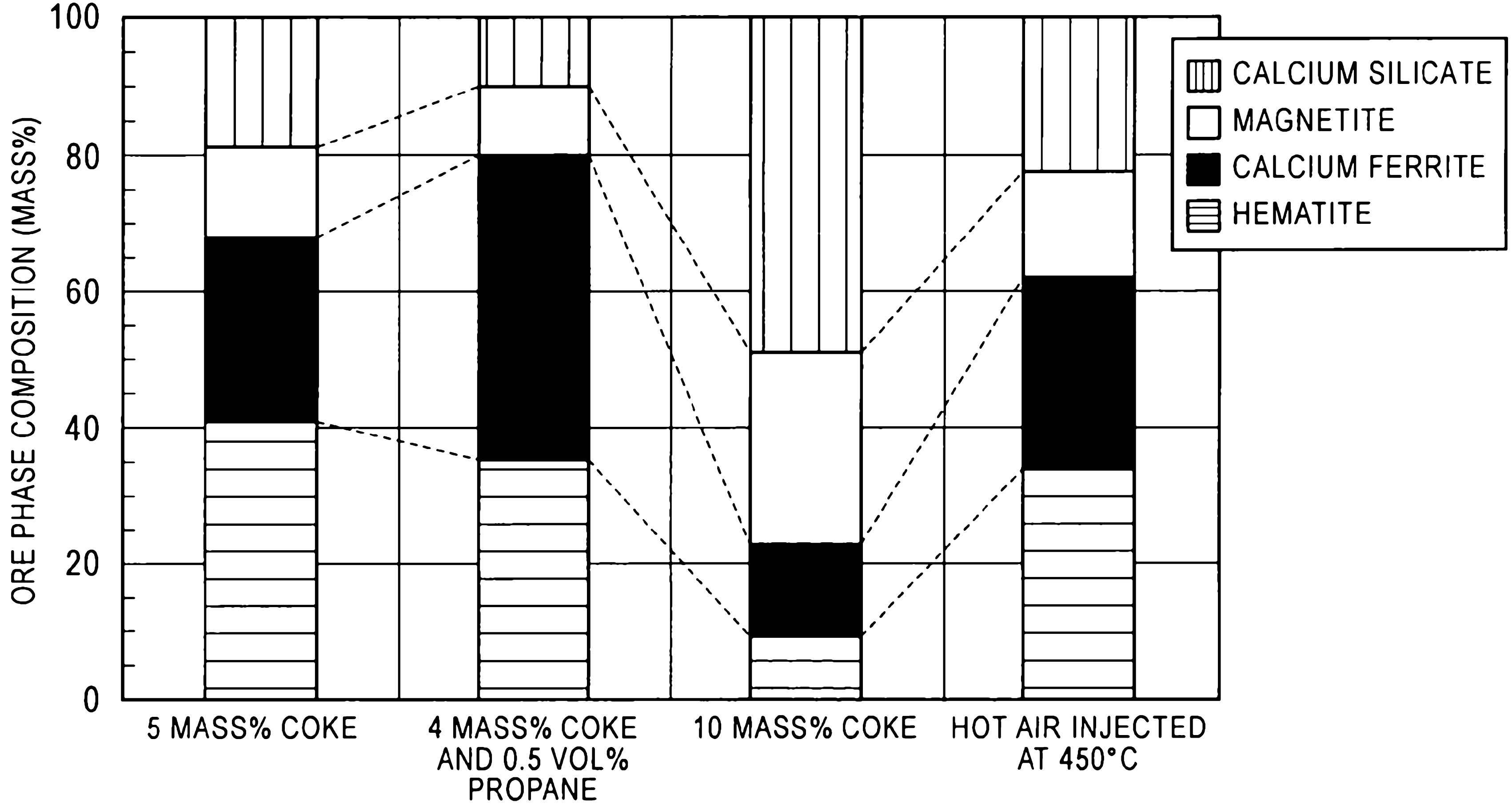
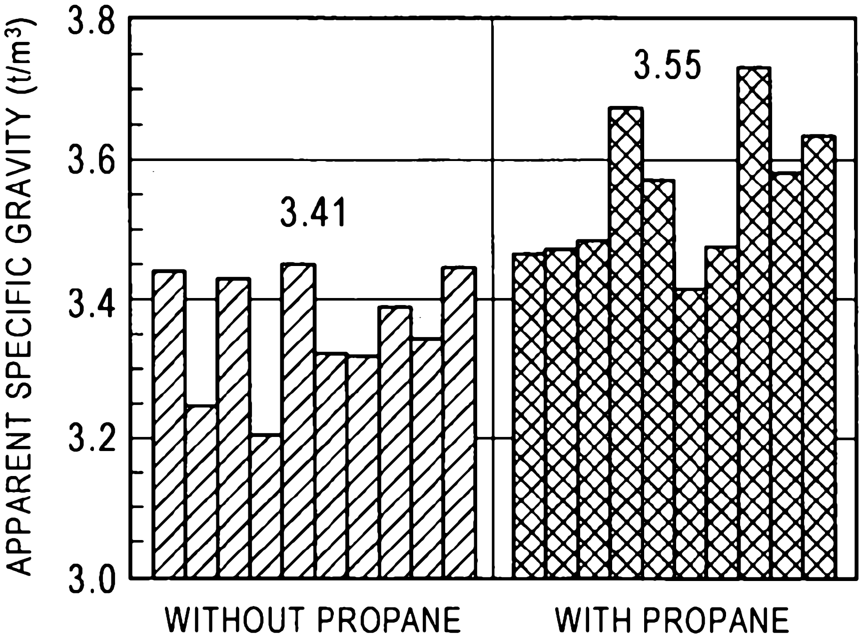
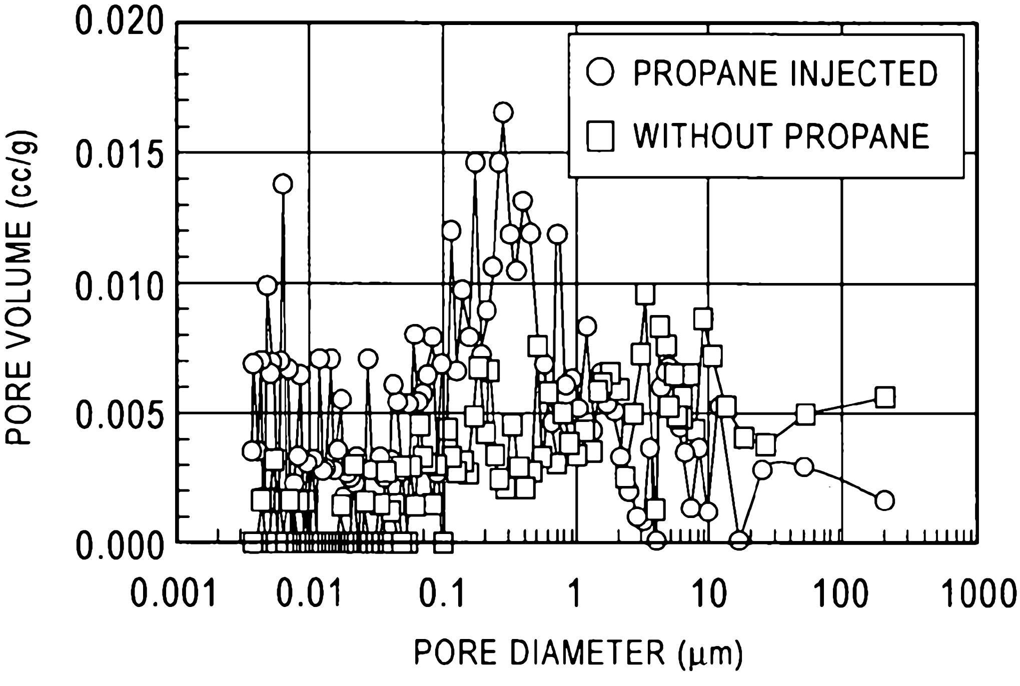

ORE PHASE COMPOSITION (MASS%)
100
80
60
40
20
0
5 MASS% COKE
4 MASS% COKE AND 0.5 VOL% PROPANE
10 MASS% COKE
HOT AIR INJECTED AT 450°C
CALCIUM SILICATE
MAGNETITE
CALCIUM FERRITE
HEMATITE

FIG. 48



APPARENT SPECIFIC GRAVITY (t/m³)
3.8
3.6
3.4
3.2
3.0
3.41
3.55
WITHOUT PROPANE
WITH PROPANE

FIG. 49



PORE VOLUME (cc/g)
0.020
0.015
0.010
0.005
0.000
○ PROPANE INJECTED
□ WITHOUT PROPANE
0.001
0.01
0.1
1
10
100
1000
PORE DIAMETER (μm)

FIG. 50

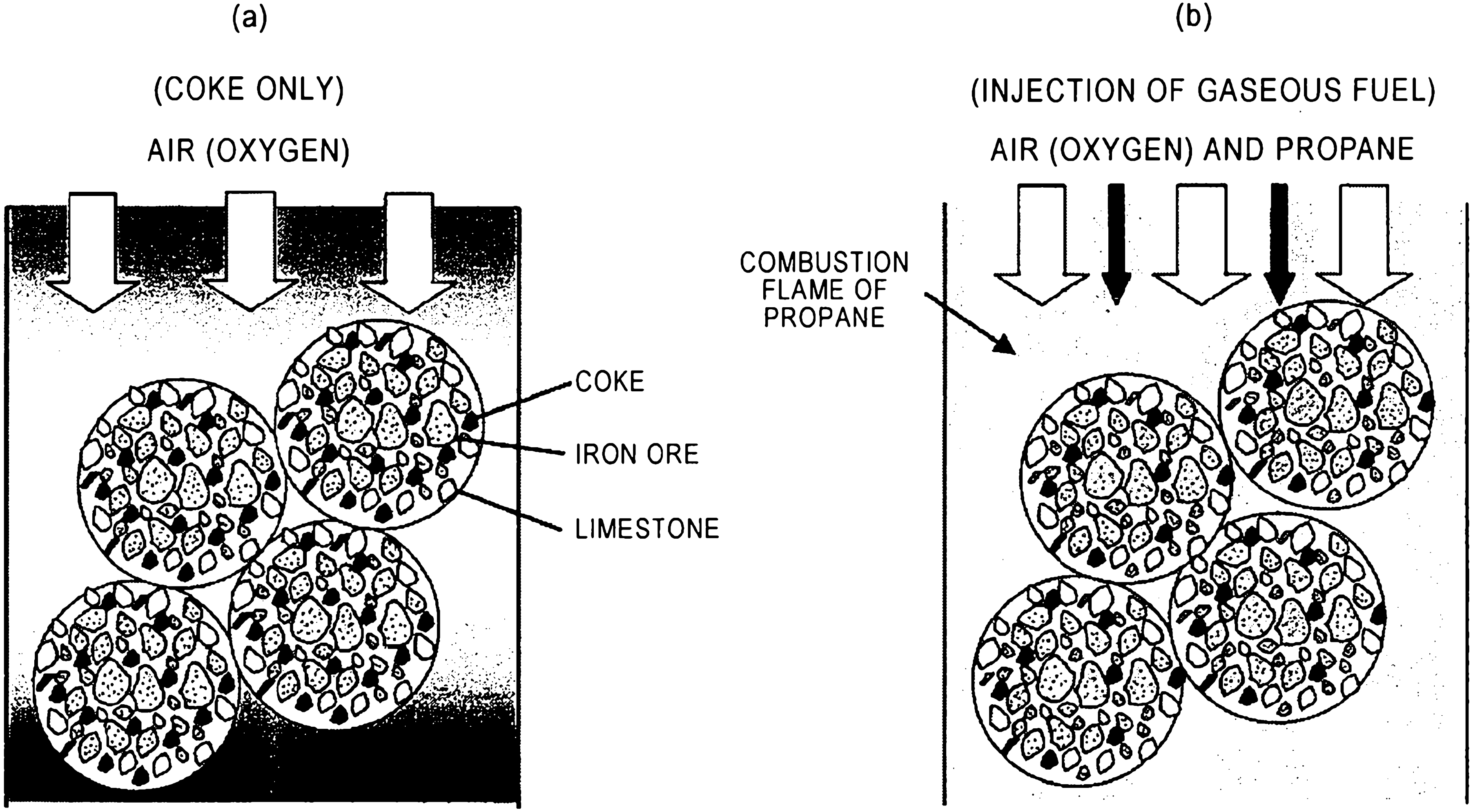

(a)
(COKE ONLY)
AIR (OXYGEN)
COKE
IRON ORE
LIMESTONE
(b)
(INJECTION OF GASEOUS FUEL)
AIR (OXYGEN) AND PROPANE
COMBUSTION FLAME OF PROPANE

FIG. 51

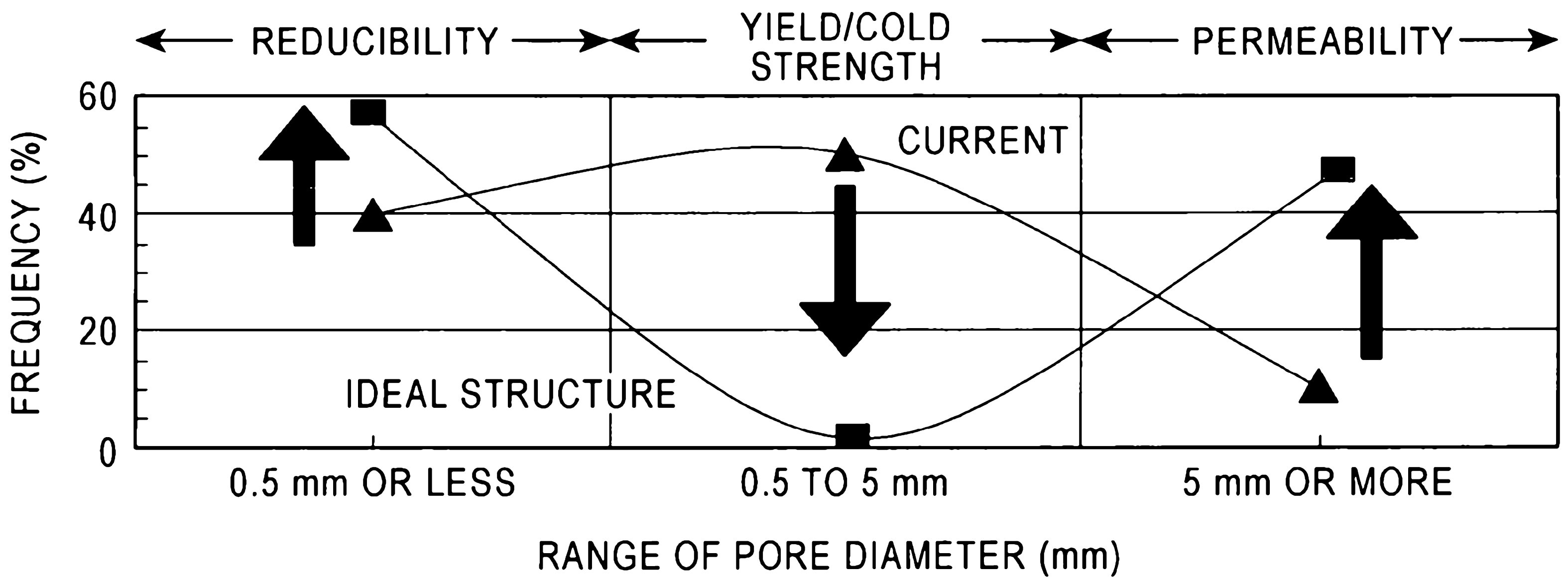

REDUCIBILITY
YIELD/COLD STRENGTH
PERMEABILITY
FREQUENCY (%)
60
40
20
0
CURRENT
IDEAL STRUCTURE
0.5 mm OR LESS
0.5 TO 5 mm
5 mm OR MORE
RANGE OF PORE DIAMETER (mm)

FIG. 52

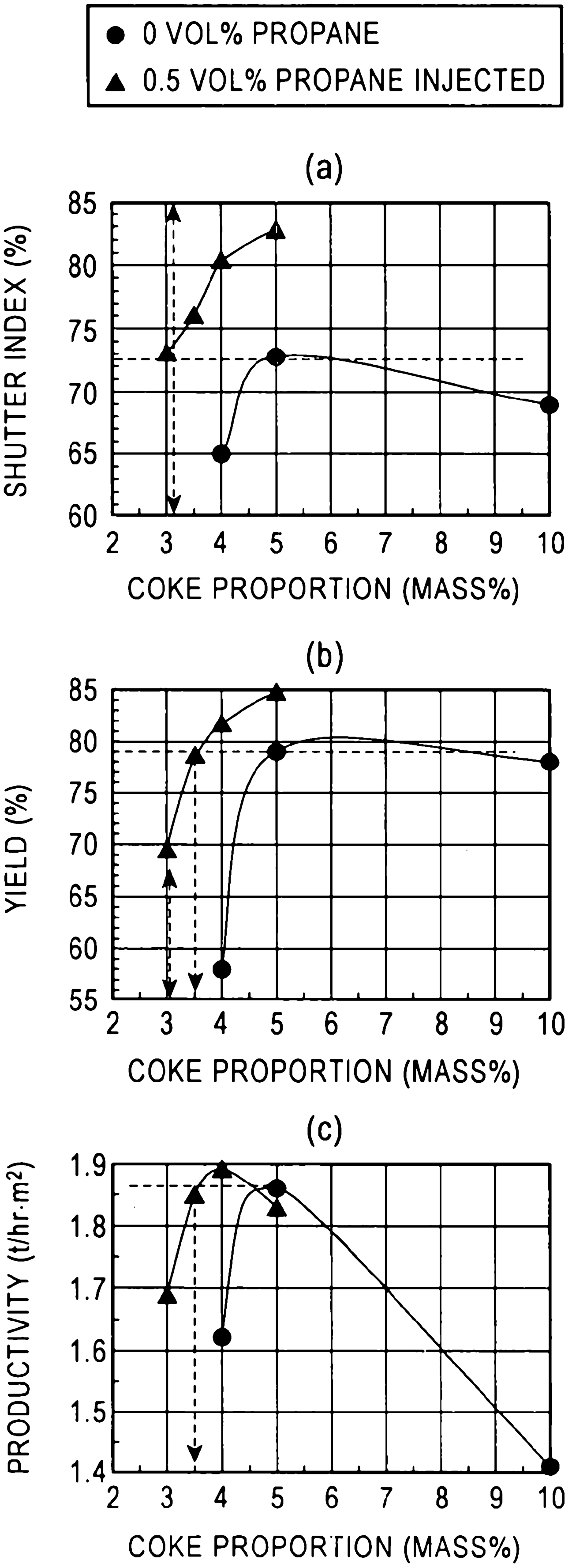
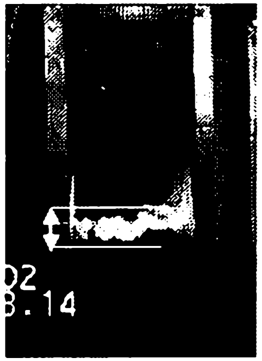
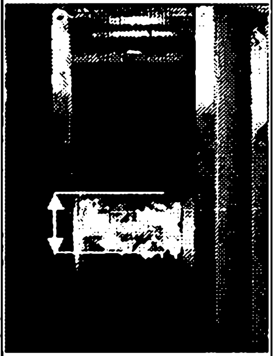
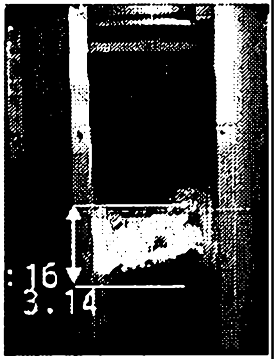
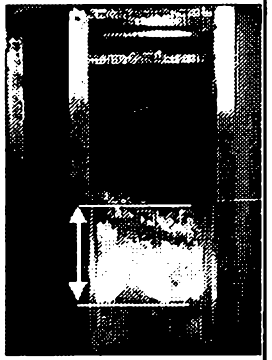
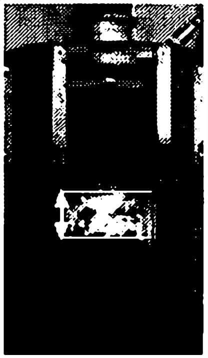
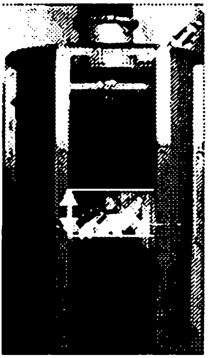
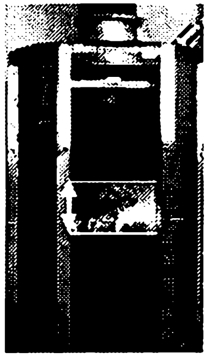
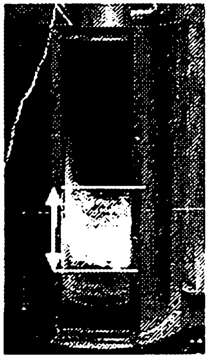

● 0 VOL% PROPANE
▲ 0.5 VOL% PROPANE INJECTED
(a)
SHUTTER INDEX (%)
85
80
75
70
65
60
2
3
4
5
6
7
8
9
10
COKE PROPORTION (MASS%)
(b)
YIELD (%)
85
80
75
70
65
60
55
2
3
4
5
6
7
8
9
10
COKE PROPORTION (MASS%)
(c)
PRODUCTIVITY (t/hr·m²)
1.9
1.8
1.7
1.6
1.5
1.4
2
3
4
5
6
7
8
9
10
COKE PROPORTION (MASS%)

FIG. 53

C-GAS CONCENTRATION (TO AIR)	0 vol%	1.0vol%	2.0vol%	2.5vol%
PROPANE CONCENTRATION ON CALORIFIC VALUE BASIS	0%	0.2%	0.4%	0.5%
COMBUSTION ZONE				
WIDTH OF COMBUSTION ZONE (mm)	50	100	135	150
SINTERING TIME (MIN.)	16.3	17.2	17.0	17.3
YIELD (%)	70.7	74.0	74.5	75.6
PRODUCTIVITY (t/hr · m²)	1.58	1.57	1.59	1.63
SHUTTER INDEX (%)	69.2	71.6	73.5	75.3

REMARKS (1) COKE RATIO: 5.0 MASS%
(2) CHARGE RAW MATERIAL: NORMAL GRANULATION
(3) BED HEIGHT: 400 mm
(4) NEGATIVE PRESSURE: 1200 mmAq
(5) INJECTION OF C-GAS: FROM 90 SECONDS AFTER COMPLETION OF IGNITION UNTIL EXHAUST GAS TEMPERATURE REACHED 70°C

FIG. 54

PROPANE CONCENTRATION (TO AIR)	0 vol%	0.02vol%	0.05vol%	0.1vol%	0.2vol%	0.5vol%
COMBUSTION						
WIDTH OF COMBUSTION ZONE (mm)	75	86	78	96	104	145
SINTERING TIME (MIN.)	15.3	15.1	15.0	14.9	15.2	18.2
YIELD (%)	65.5	65.6	64.8	67.0	68.4	68.3
PRODUCTIVITY (t/hr · m^2)	1.47	1.48	1.47	1.51	1.54	1.44
SHUTTER INDEX (%)	71.8	76.6	76.0	75.8	77.9	82.9

REMARKS
(1) COKE RATIO: 5.0 MASS%
(2) CHARGE RAW MATERIAL: COKE FINE AND LIMESTONE COATING
(3) BED HEIGHT: 400 mm
(4) NEGATIVE PRESSURE: 1200 mmAq
(5) INJECTION OF PROPANE: FROM 60 SECONDS AFTER COMPLETION OF IGNITION UNTIL EXHAUST GAS TEMPERATURE REACHED 70°C